FEBRUARY, 1958

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4 GROSVENOR GARDENS · LONDON SW1

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VOL. 188 PART 2

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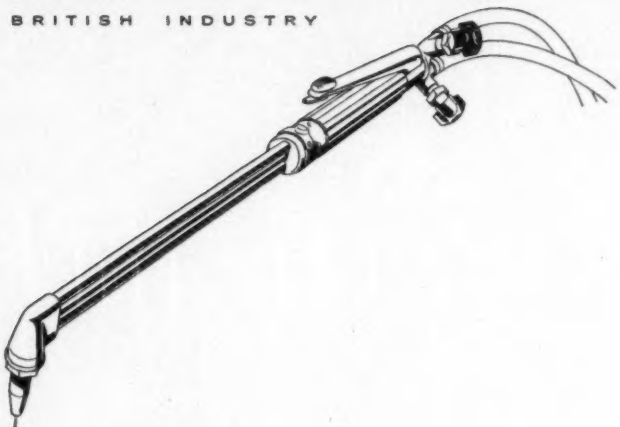
FROM BRITISH OXYGEN - FOR BRITISH INDUSTRY



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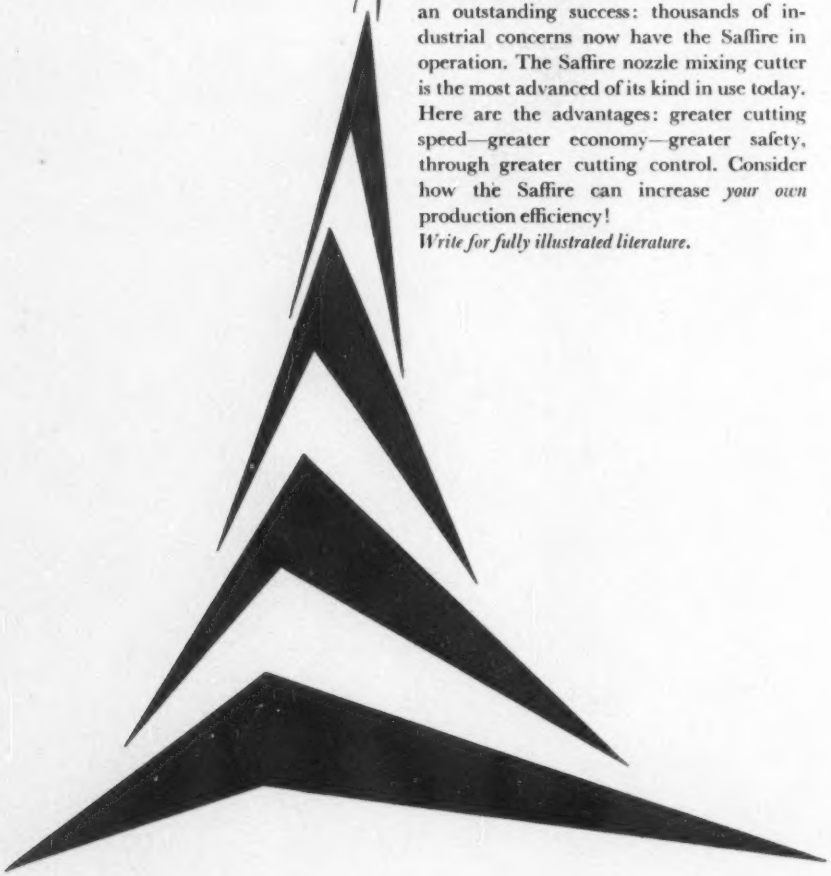

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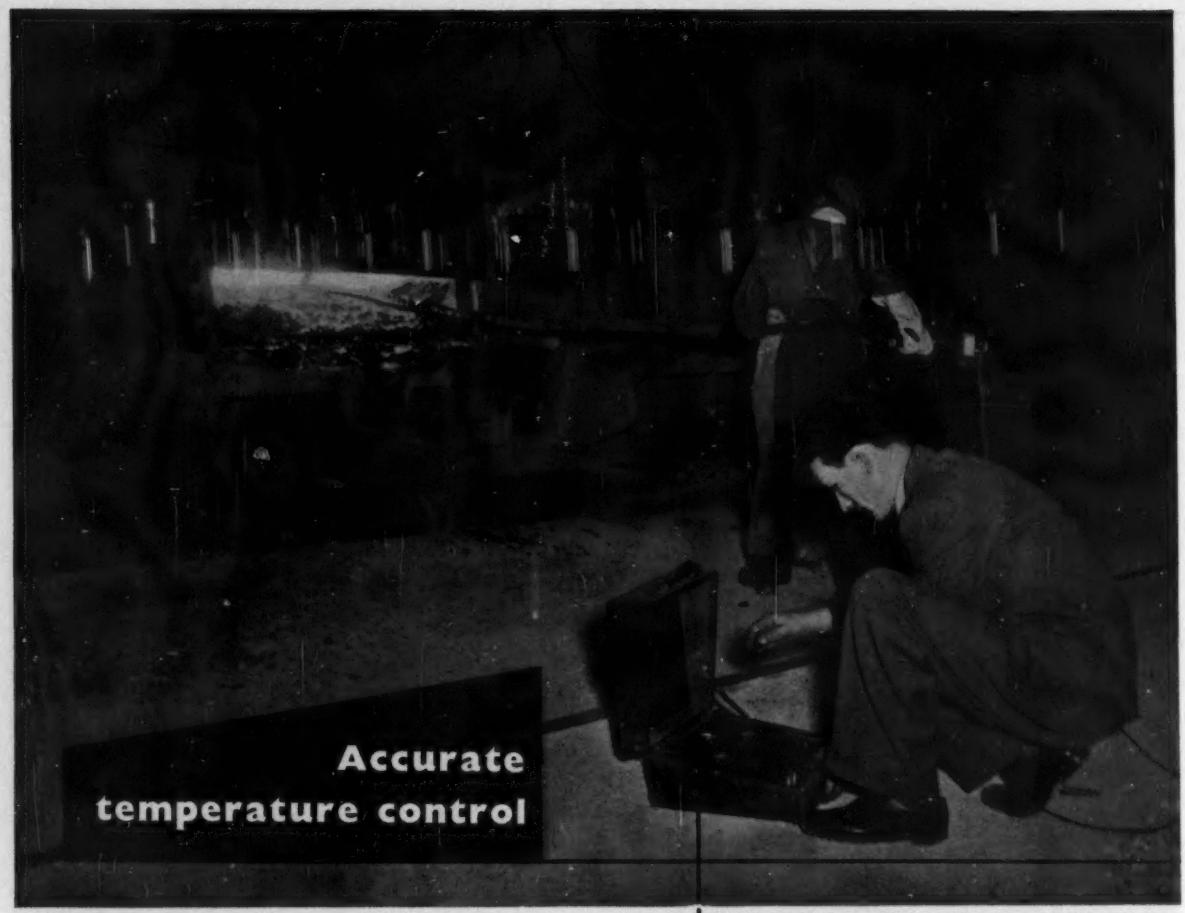

Photograph of a quick immersion thermocouple in use in an open hearth furnace, shown by courtesy of Appleby-Frodingham Steel Co. Ltd.

The use of Platinum v Rhodium/Platinum Thermocouples within the steel industry has greatly assisted in the production of finer, more uniform steels, by providing a more accurate and reliable method of temperature determination than was formerly possible.

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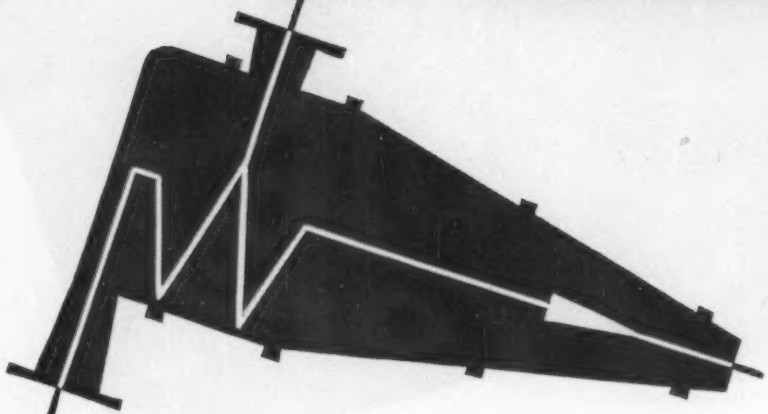

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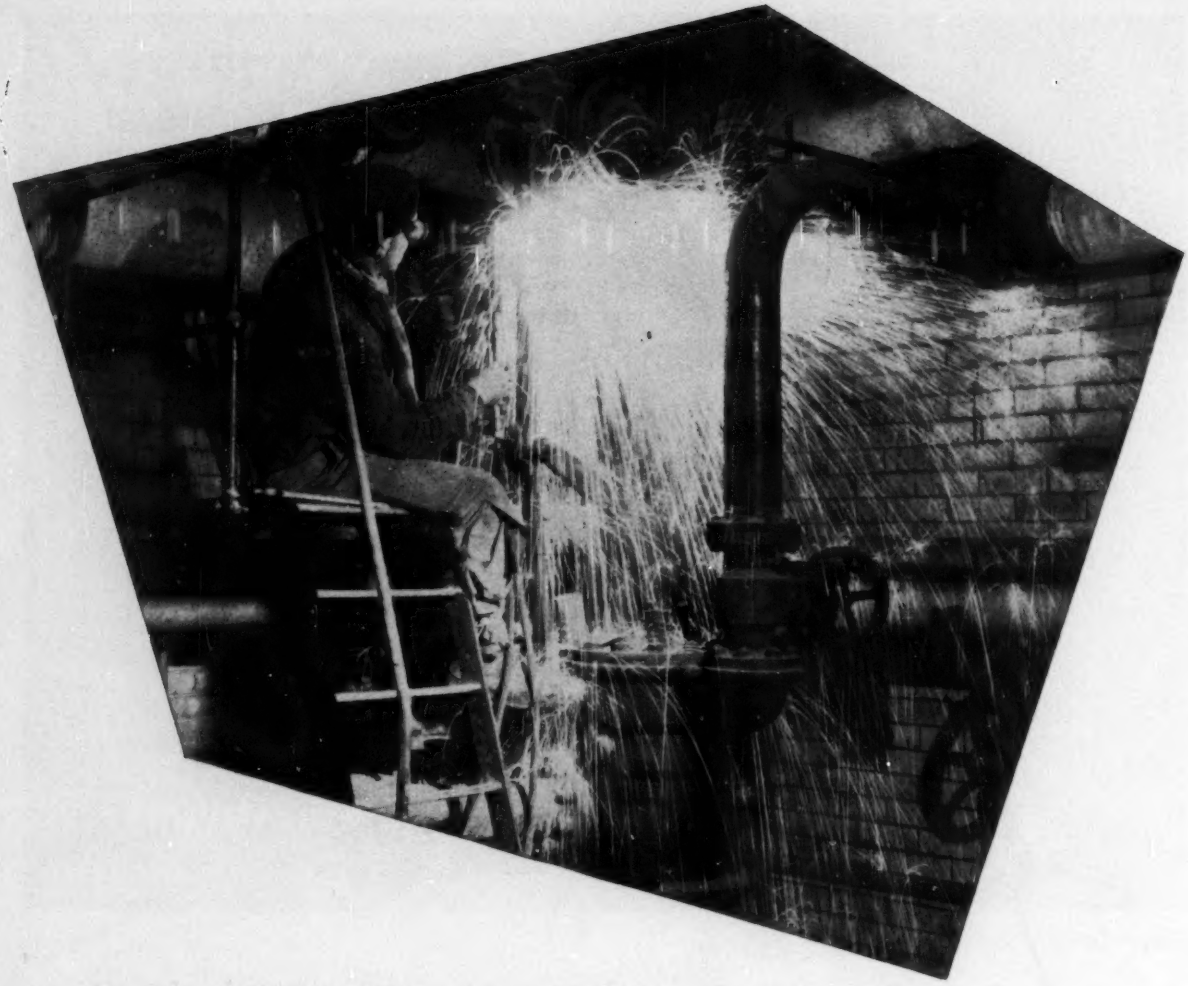

Making way for Modern Plant

Skill in dismantling consists of tackling a destructive job in a constructive manner and in obtaining maximum recovery and re-use of plant and machinery. Above is a typical example of Wards at work dismantling equipment in connection with the removal of large boilers and generating plant. Whenever there is a dismantling job to be done it is good business to remember this aspect of the Ward Group service.

WARDS **WORKS DISMANTLING DEPARTMENT**

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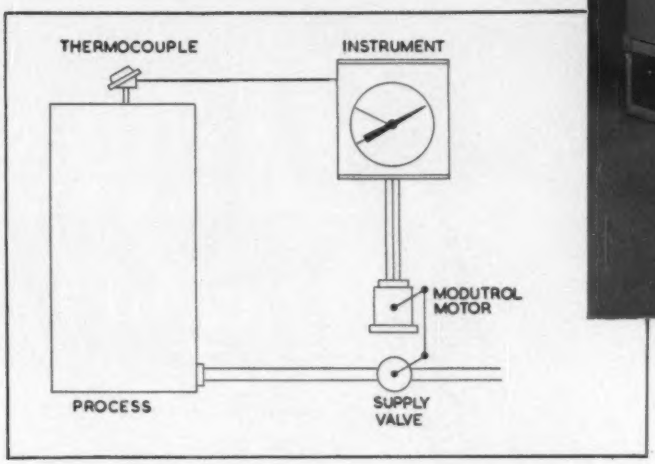
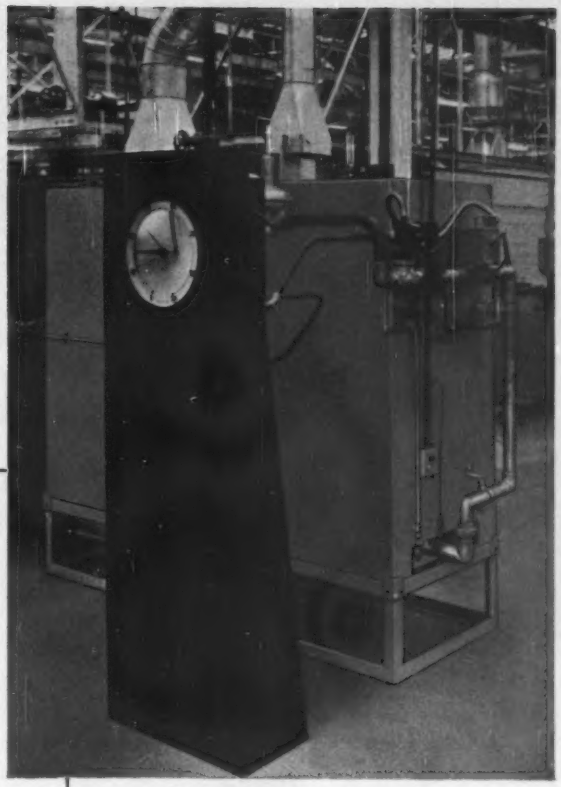
Vauxhall Motors choose Honeywell's Non-cycling Temperature Control System





At Vauxhall Motors many gas-fired furnaces are now temperature controlled by a simple Honeywell non-cycling system.

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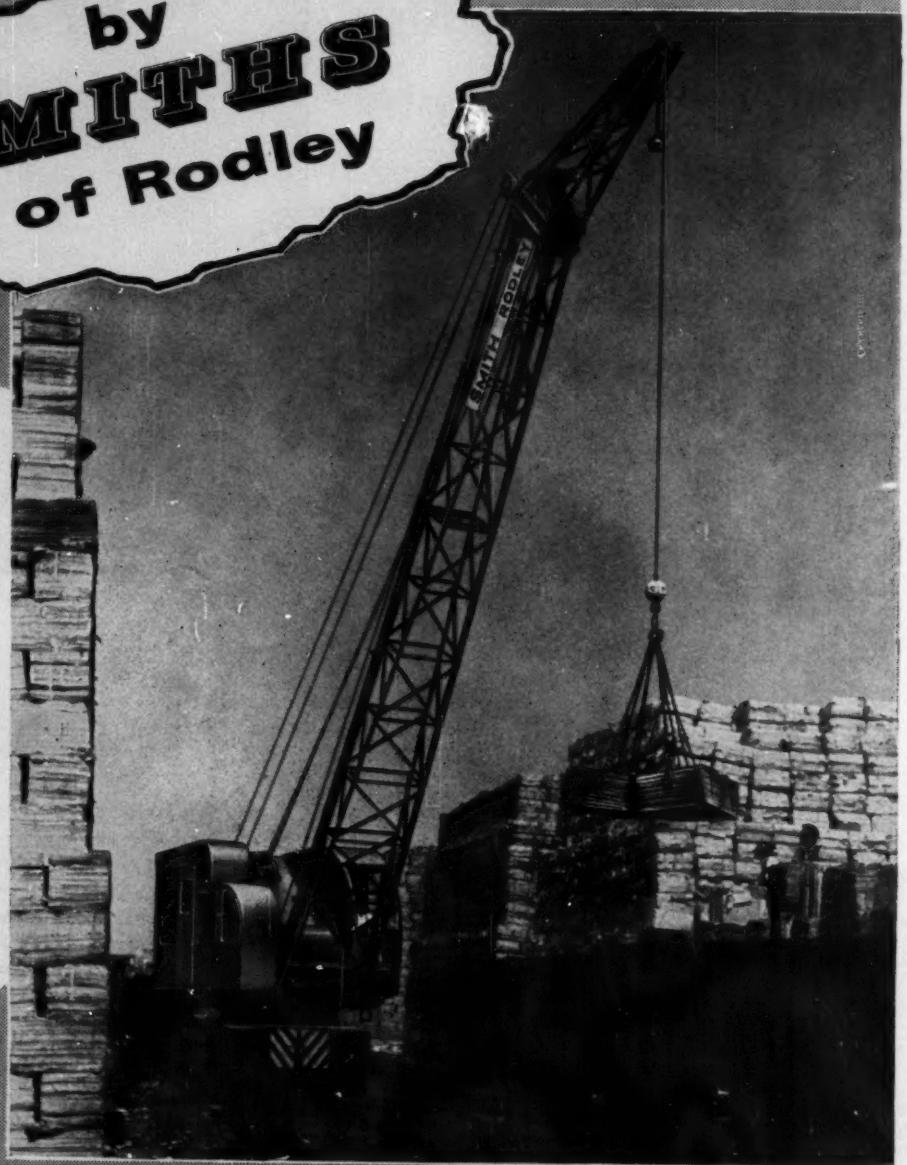
by SMITHS of Rodley



Smith Diesel and Diesel-Electric locomotive and shunting cranes serve many industries, particularly engineering and steelworks, docks and railways, stockyards, etc. Photograph at right shows a Smith 3-ton Diesel shunting crane engaged on stacking duties at a large paper mill in Lincolnshire. Using a 30 ft. cranked jib, it lifts 3 tons at 22 ft. radius. The very fast hoisting speed (200 f.p.m.) is ideal for this class of work.

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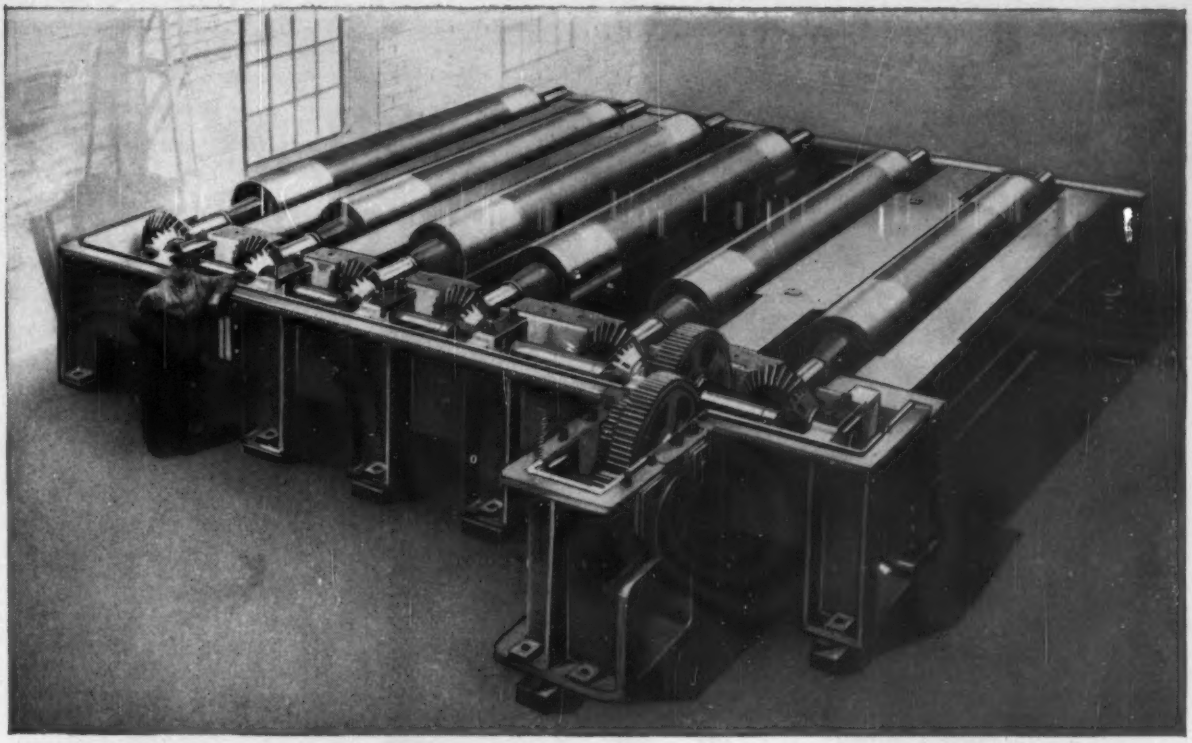

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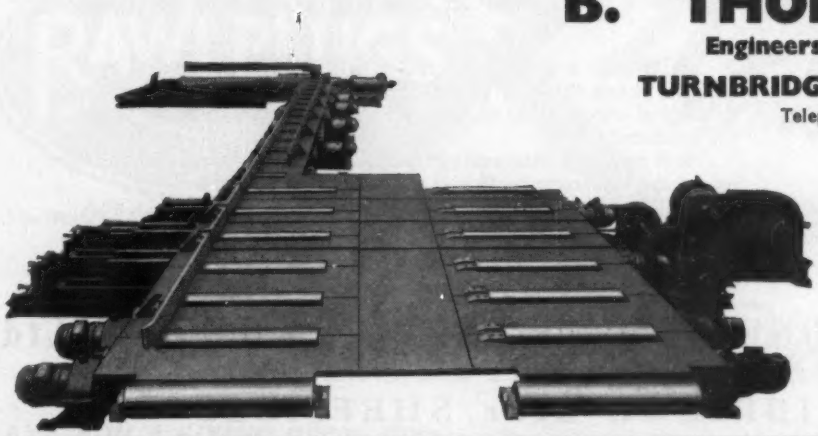

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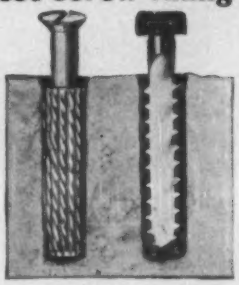
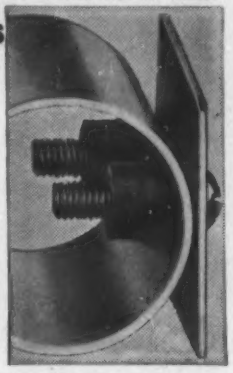


For Cavity fixings

For almost impossible jobs use the Rawlnut. (You can even make a fixing to a pipe). The tapped nut in the end of the rubber bush is drawn up to the reverse face of the material by turning the screw. The result is an airtight, watertight, vibration-proof fixing of enormous strength. For thin plastic, metal, wallboard and hollow pot, etc., it is invaluable.



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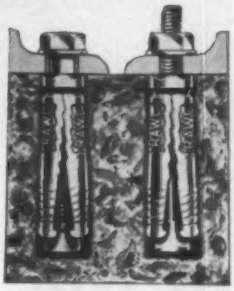

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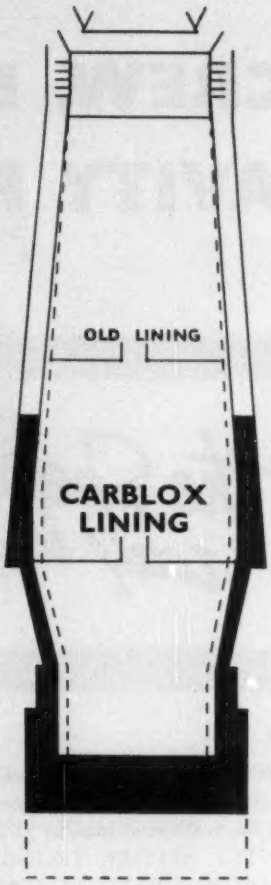

To increase productivity have a thinner lining in the same furnace shell by using CARBLOX

For the
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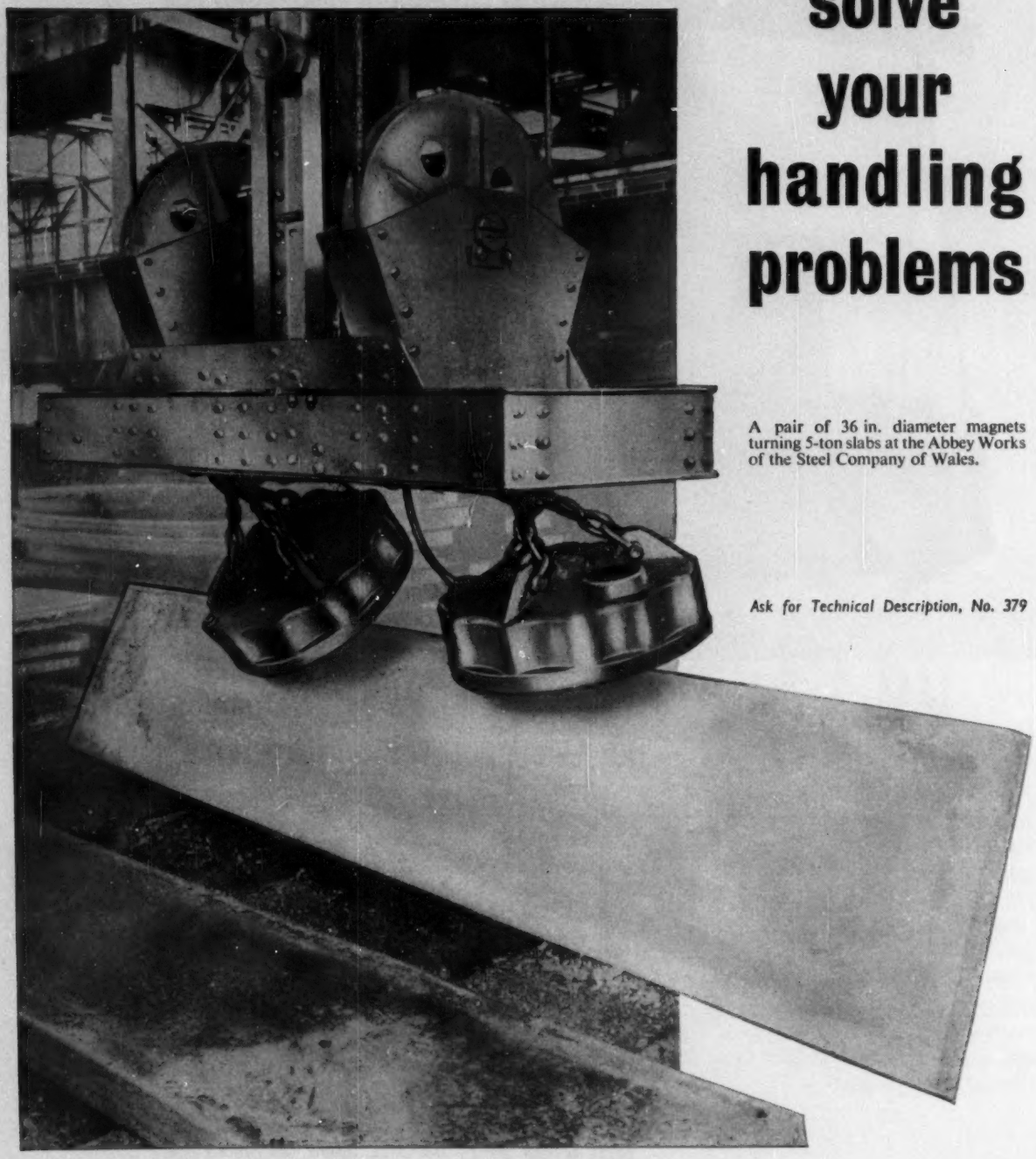

A pair of 36 in. diameter magnets turning 5-ton slabs at the Abbey Works of the Steel Company of Wales.

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triple draw bar drawbenches

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Simple and efficient bar ejection

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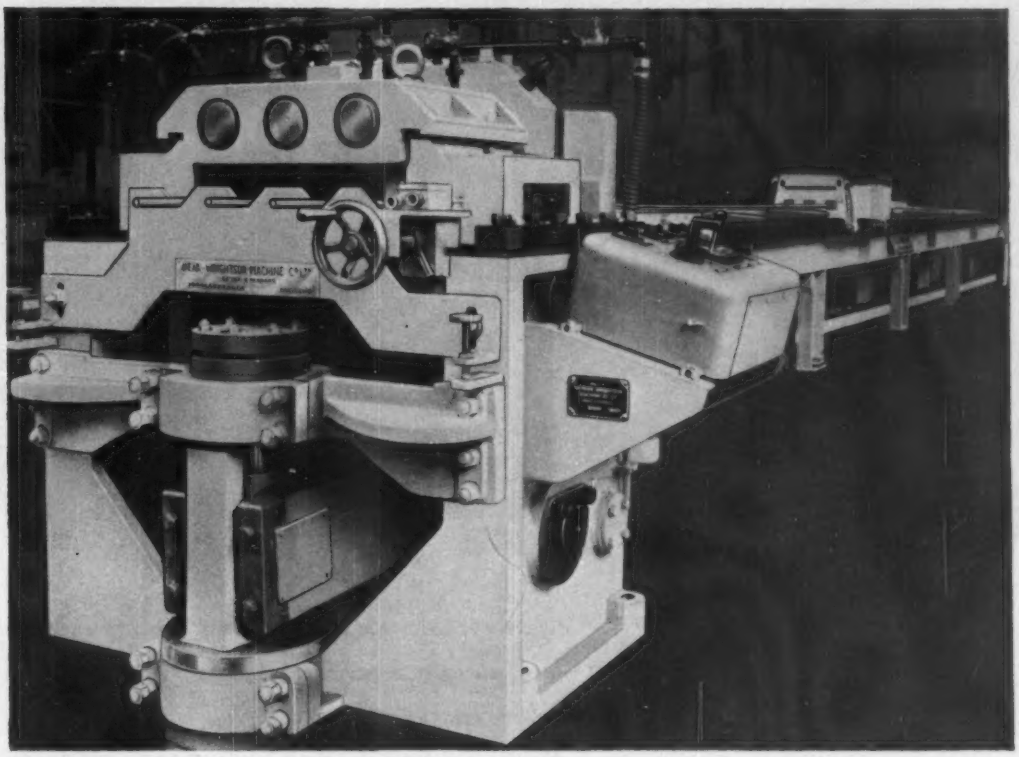

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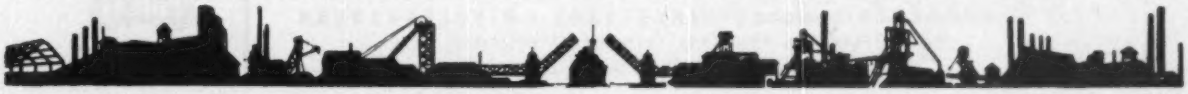

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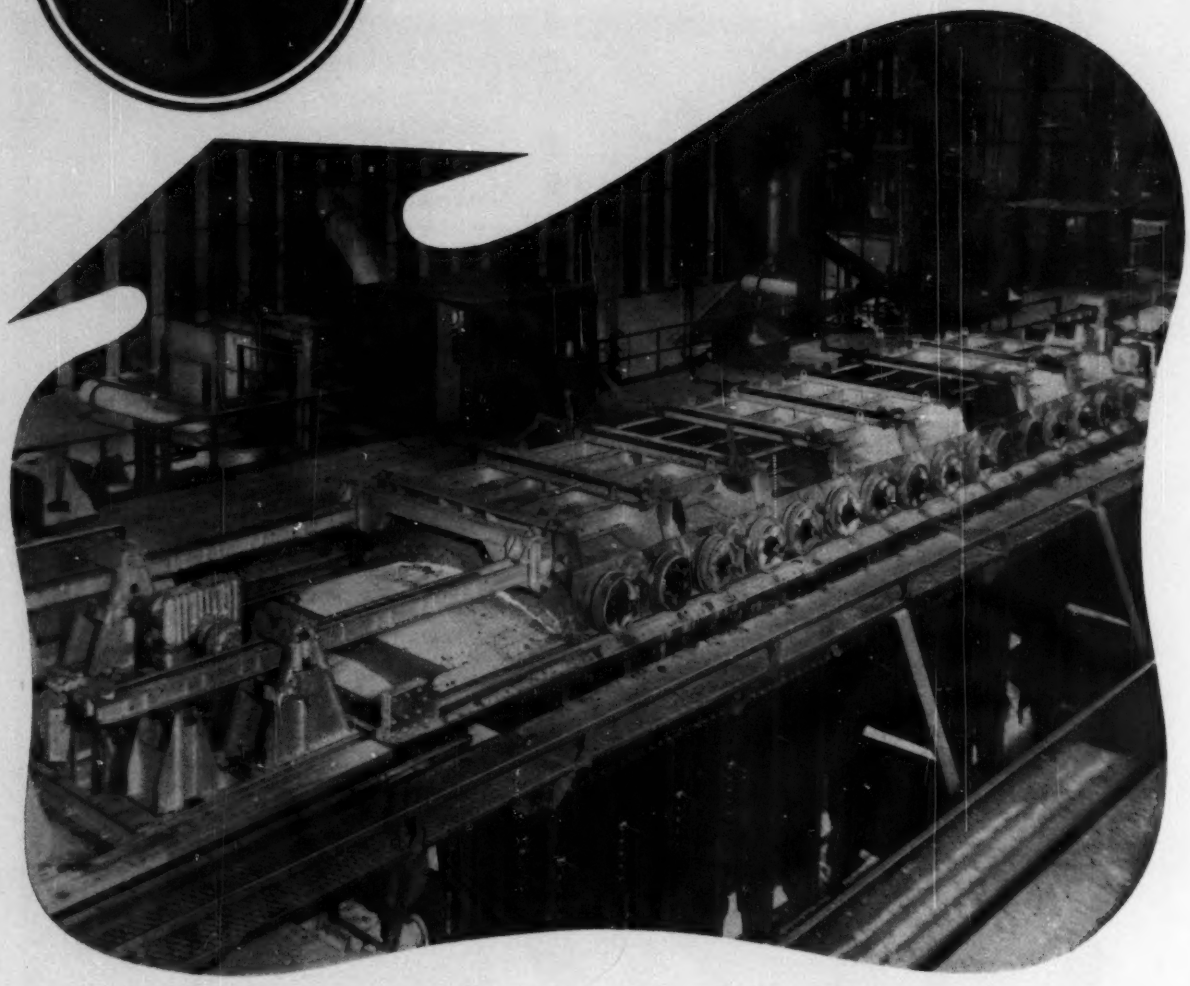
PRIEST

SOAKING PITS



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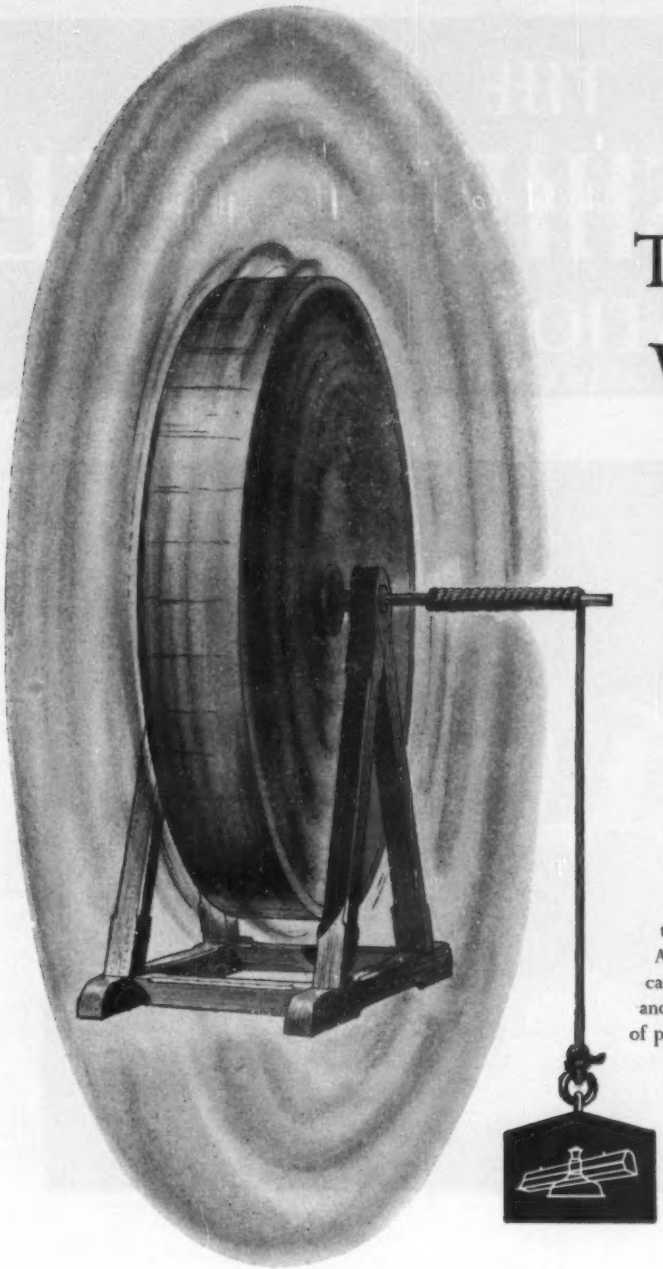

The Wheel Of Orffyreus

In the 18th century
Johann Ernest Elias Bessier—
known as Orffyreus—invented a wheel that,
once started, went on and on . . . and on.
Between 1712 and 1717 Orffyreus made four
such wheels, the last subjected to rigid
examination by scientists and experts,
then placed in an empty, sealed room
for two months. On re-entry
the wheel was found, still spinning.
A fit of rage over continuing scepticism
caused Orffyreus to smash his invention
and he died in 1745, taking his secret
of perpetual motion with him.

In a similar manner Benjamin lighting fittings
last indefinitely. The 'Crysteel' vitreous enamel
finish will not deteriorate but will give
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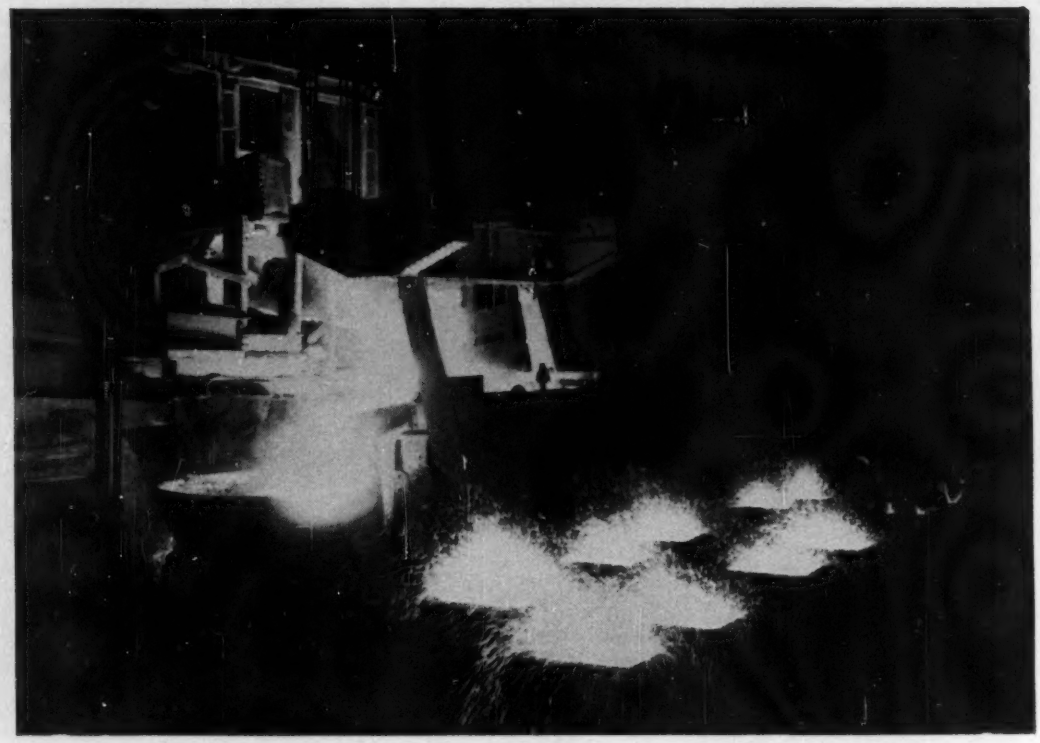

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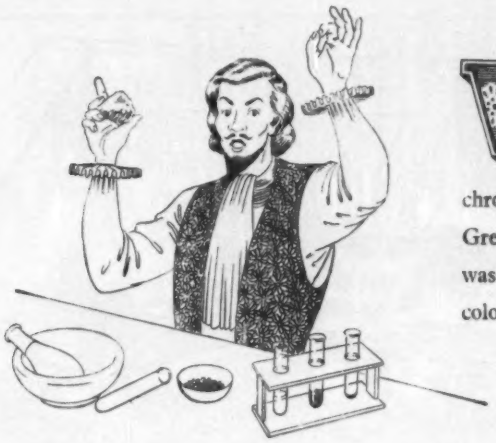

Vauquelin, a French chemist, discovered chromium in 1797. The word is derived from the Greek ' chroma ' meaning colour, and the root was appropriate because of the new element's many coloured compounds.

Twenty-four years went by however before the first alloys of chromium were produced. Berthier was responsible for this great advance and contributed even more to progress by preparing the first chromium steels; he appreciated the improved properties imparted to steel by chromium.

An event of the utmost importance in the history of chromium steels was the construction of the famous Eads Bridge over the Mississippi River at St. Louis in 1874. It was indeed an imaginative and somewhat daring project for commercial production of chromium steels did not become general for another 25 years.

Need it be stated that *Union Carbide* have an axe to grind? Probably not, but nevertheless it is worthy of note that they are amongst the world's largest suppliers of chromium alloys and metals.

The term ***UNION CARBIDE*** is a trade mark

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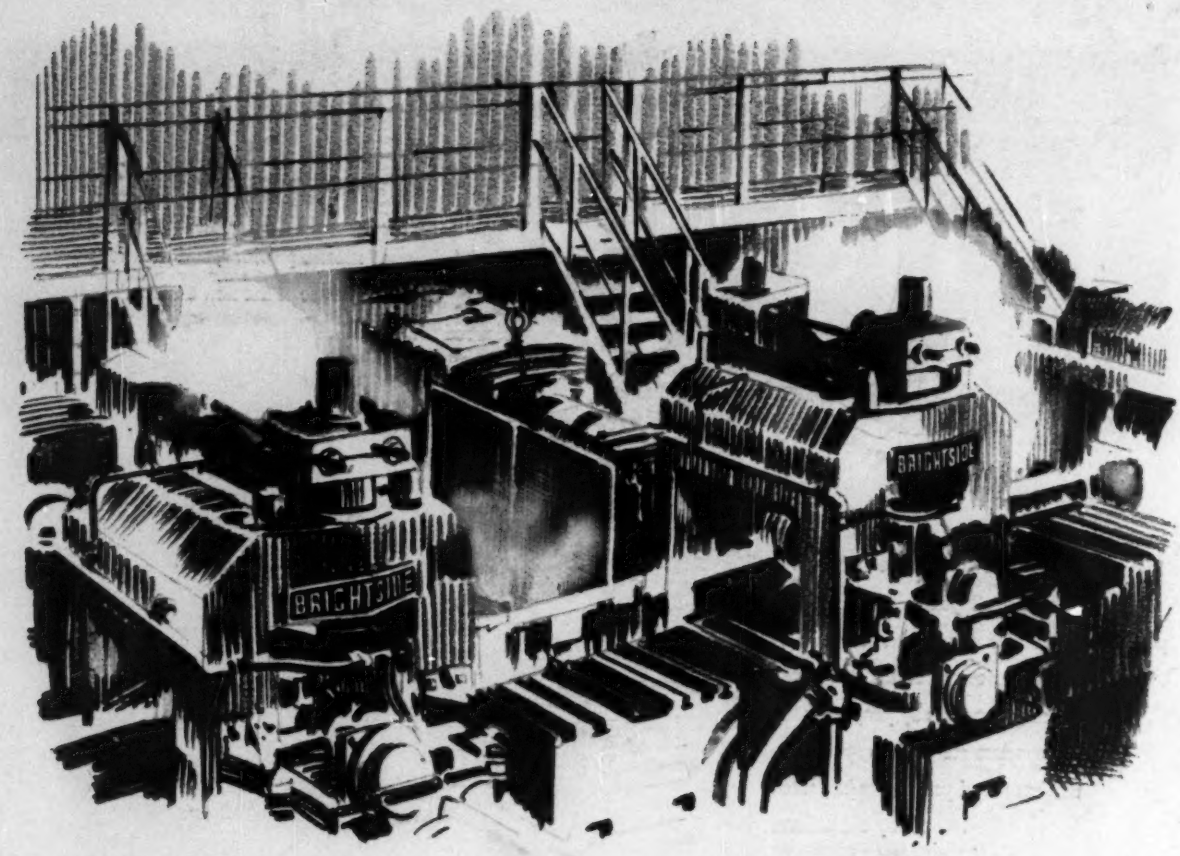
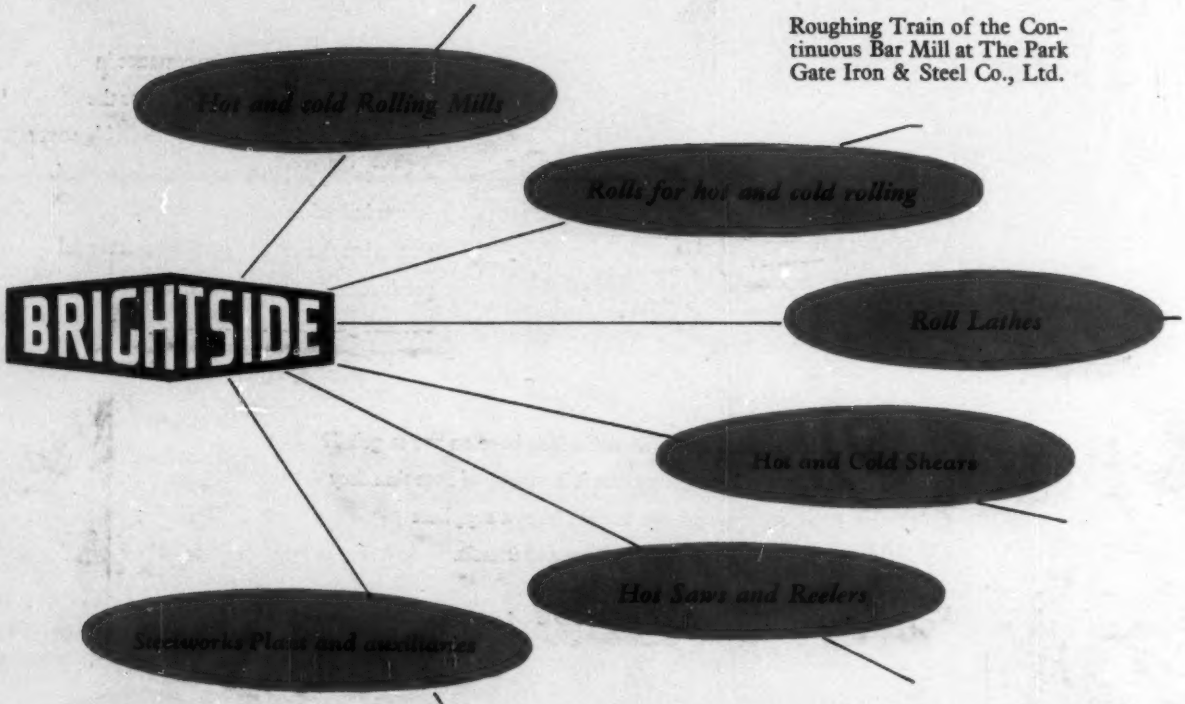


Roughing Train of the Continuous Bar Mill at The Park Gate Iron & Steel Co., Ltd.



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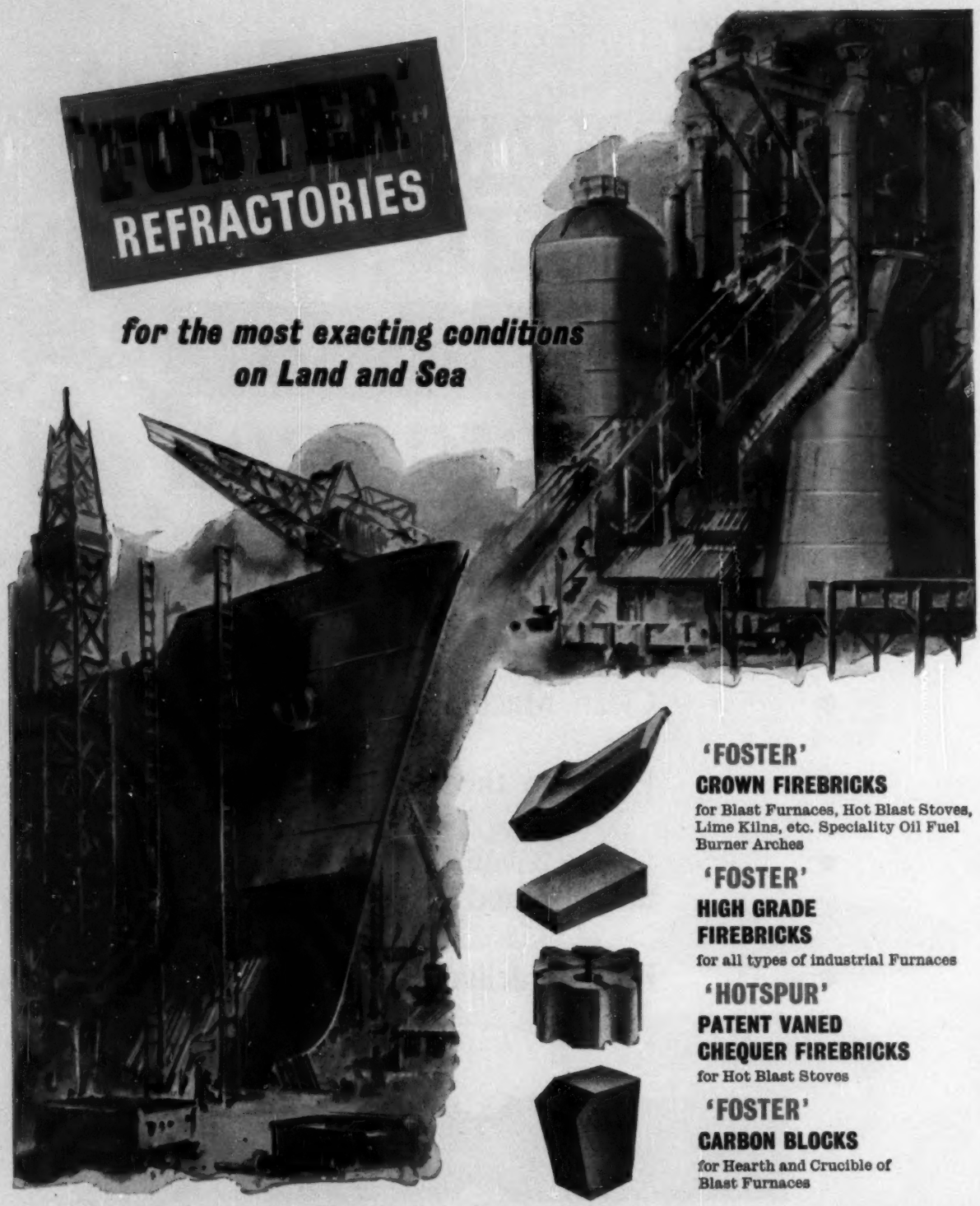

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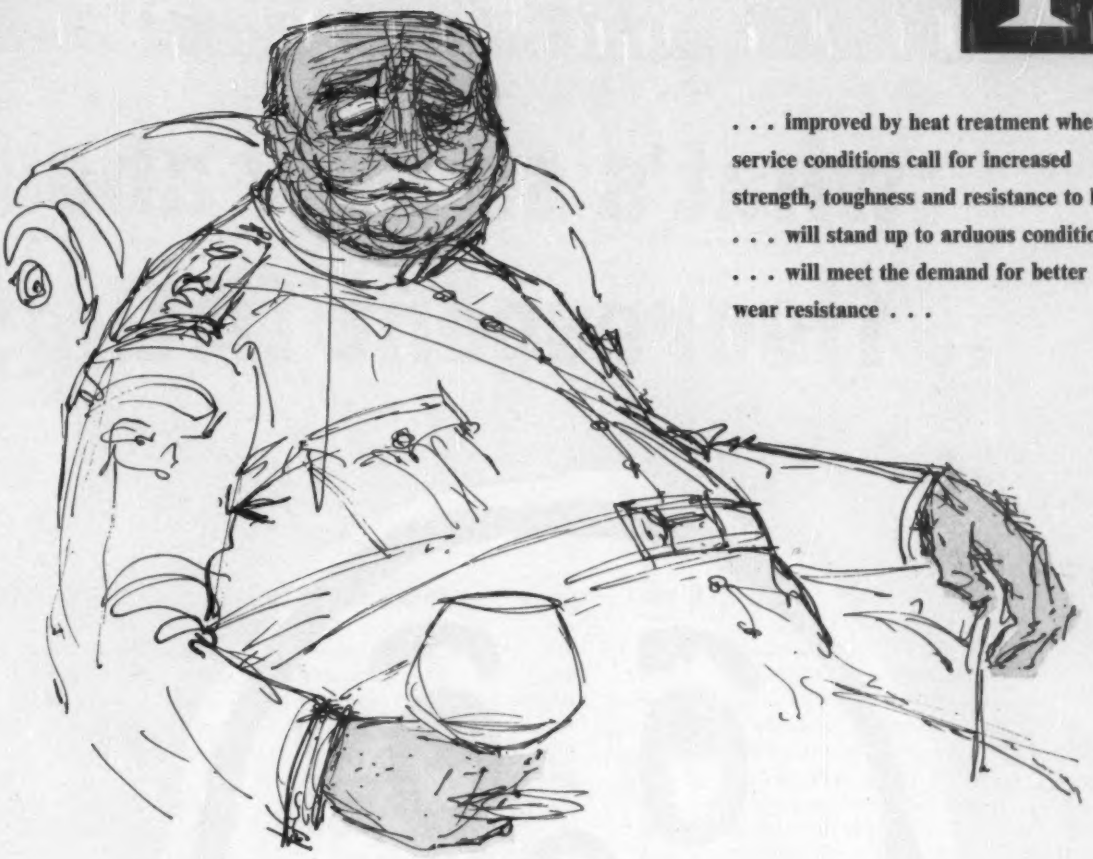

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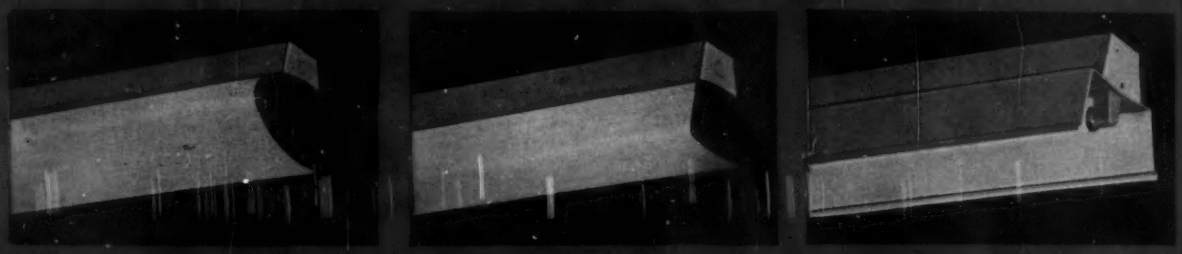

what's so new about fluorescent fittings

THE GENERAL ELECTRIC CO. LTD.,

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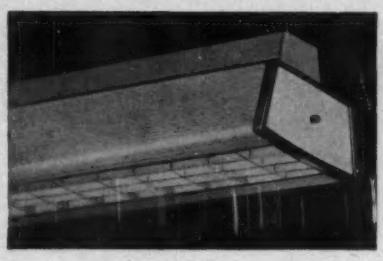

these anyway?

Everything is new! *The '101 Range' is an entirely new range of contemporary styled industrial, commercial and decorative fluorescent fittings. The successful result, in fact, of team work between G.E.C. fittings designers and illuminating engineers. Competitively priced—outstandingly modern in conception! NEW also is the introduction of basic channels for single or twin tubes, 1½ ft. to 8 ft. which, with specially designed attachments, form an interchangeable system of great versatility with particularly simple installation and maintenance. It is important that you learn all about this exceptional range —the '101 Range'—of G.E.C. fluorescent fittings, so write for fully descriptive catalogue No. F 4068.*

new adaptability

The G.E.C. '101 Range' sets a *new standard* of adaptability. Using as a basis, channels of common cross section, industrial, commercial and decorative fittings are built without a multitude of small parts. Each is a soundly engineered fitting, of modern appearance and incorporates many aesthetic and mechanical refinements. Installation and maintenance are absolutely simple.

new reflectors

For the first time the industrial user can have vitreous enamelled closed end trough reflectors made from a single pressing, with well-rounded corners and without joints. They are therefore particularly easy to clean. New techniques enable them to be made lighter than previous types and therefore easier to handle and less susceptible to damage.

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Recessed double contact (R.D.C.) caps are fitted to OSRAM 8 ft. 125 w. tubes for use in the '101 Range'. This new cap design protects the tube ends and allows replacement by one person from one ladder position. Recessed double contact caps also provide firm, reliable support and location for these tubes without relying on contact pins or independent clips. This results in easier tube replacement after cleaning or maintenance. Unsightly shadows are reduced, as the new cap gives a smaller "dead region" at tube ends. Osram Guaranteed Tubes, with their freedom from early failures, are recommended for all G.E.C. lighting fittings.

G.E.C. range 101

fluorescent fittings

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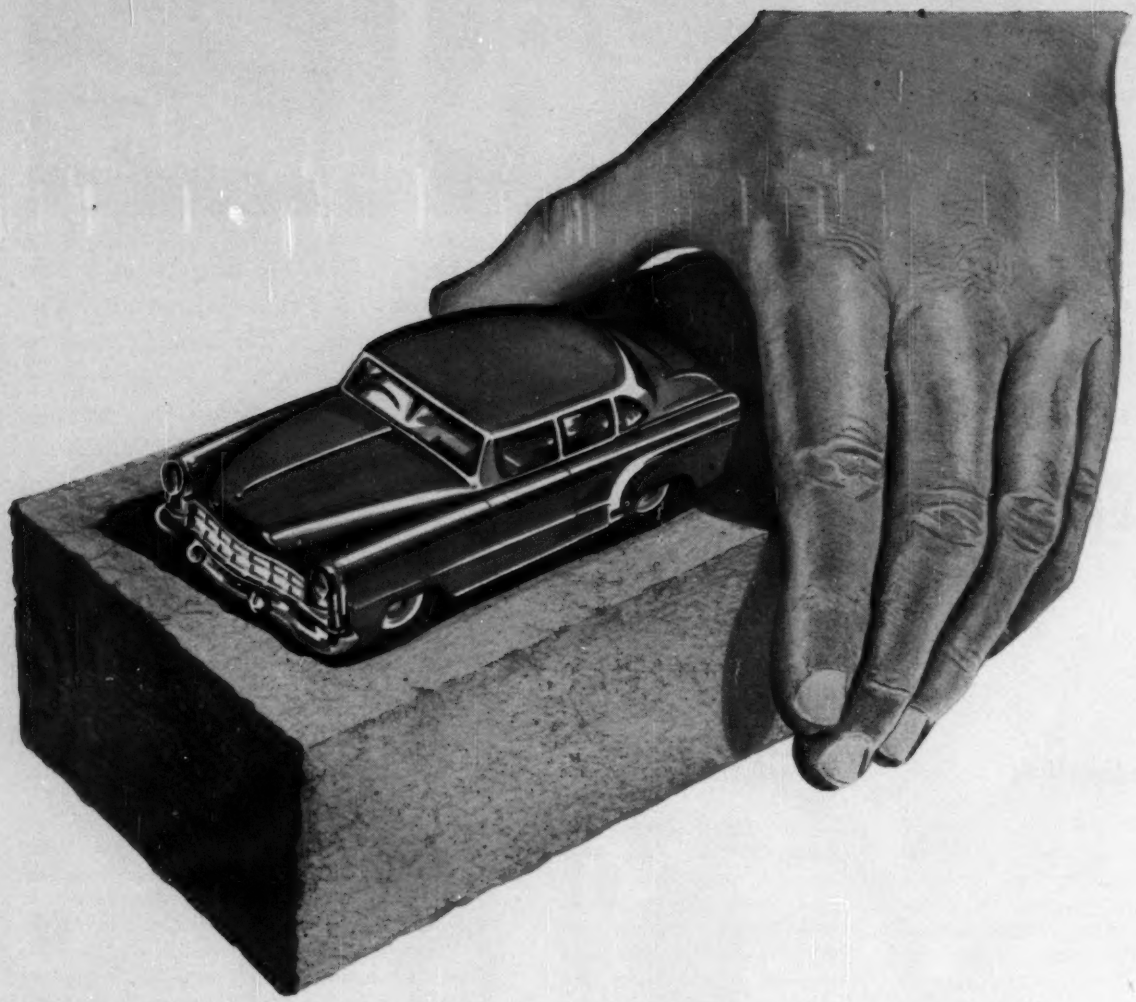

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Furnace tapping in the Electric Arc Melting Shop of Messrs Thos Firth & John Brown Ltd Sheffield, by whose courtesy this photograph is reproduced.

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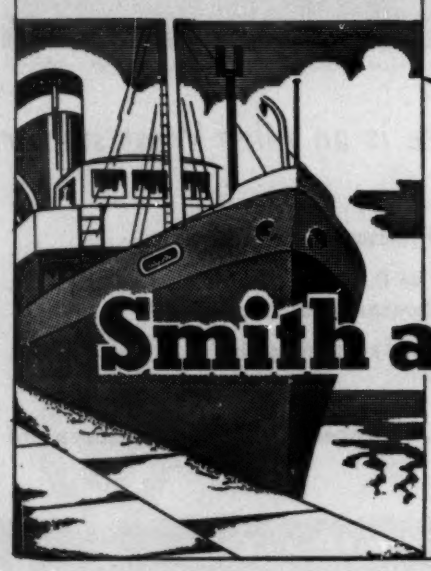

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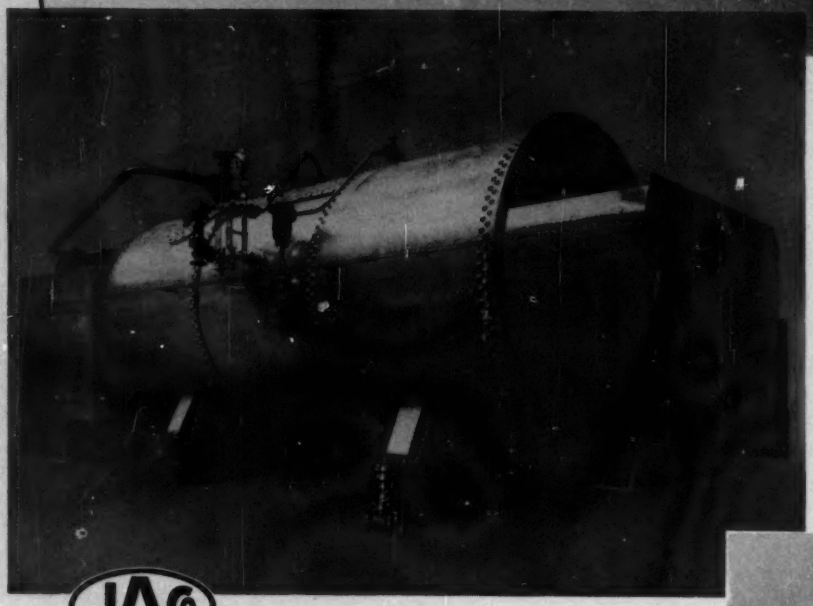


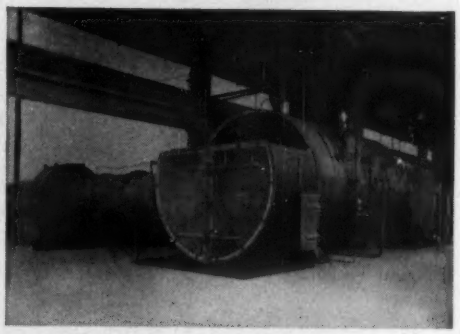
The new, revised edition of our booklet "The Choice of a Boiler" gives a concise summary of various types of shell boiler, and will be sent to responsible engineers, etc., writing on firms' letter headings.

JAC

The Joseph Adamson Waste Heat Boiler is designed to make efficient use of the waste gases leaving open-hearth furnaces, reheating furnaces, soaking pits, gas retorts, etc.

The straight-through fire tubes have a high ratio of length to bore, giving about 90% tube efficiency and providing a large area of heating surface in a comparatively small space. Brickwork setting is not required and air infiltration is thus avoided.

A feature of Joseph Adamson Waste Heat Boilers is that a special cleaning device can be provided in the outlet chamber to allow the tubes to be cleaned while the boiler is at work.



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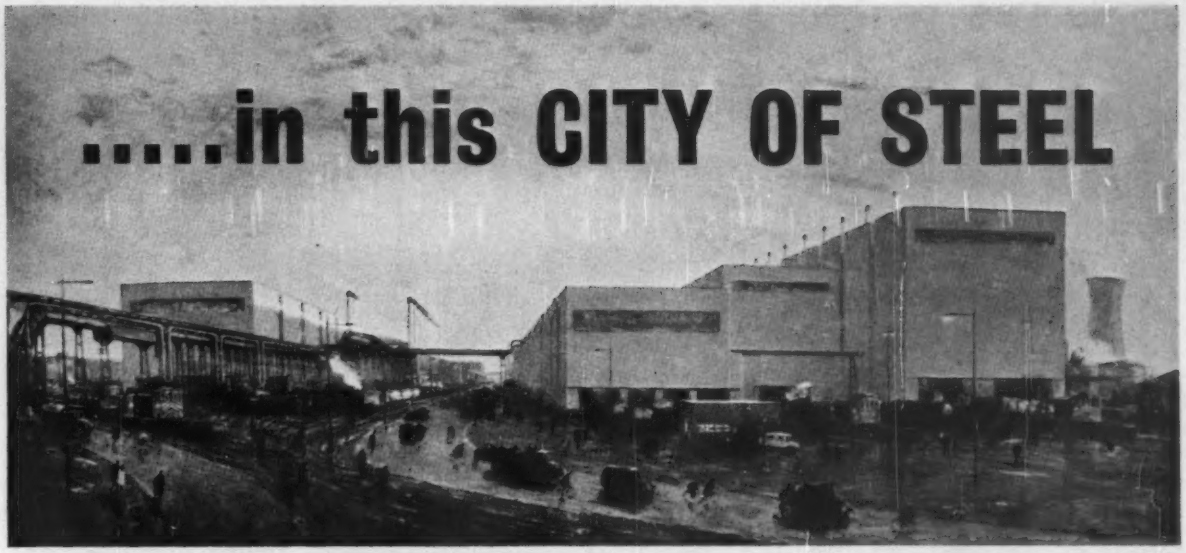
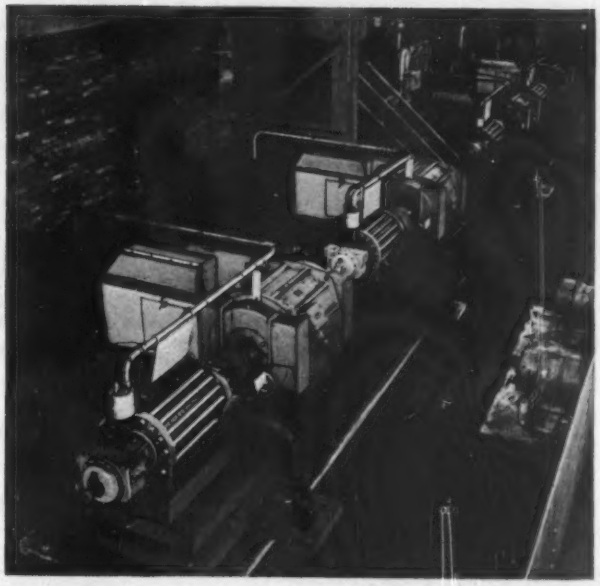


EUROPE'S LARGEST HYDRAULIC DESCALING PLANT WAS ENGINEERED BY

The 10 stand continuous wide strip mill at the Abbey Works of The Steel Company of Wales incorporates the Harland descaling system. Spiroglide multistage pumps for a duty of 1,000 g.p.m at 1,250 p.s.i. with 1,250 h.p., totally enclosed, water cooled, direct-on-line starting motors supply the high pressure descaling nozzles.



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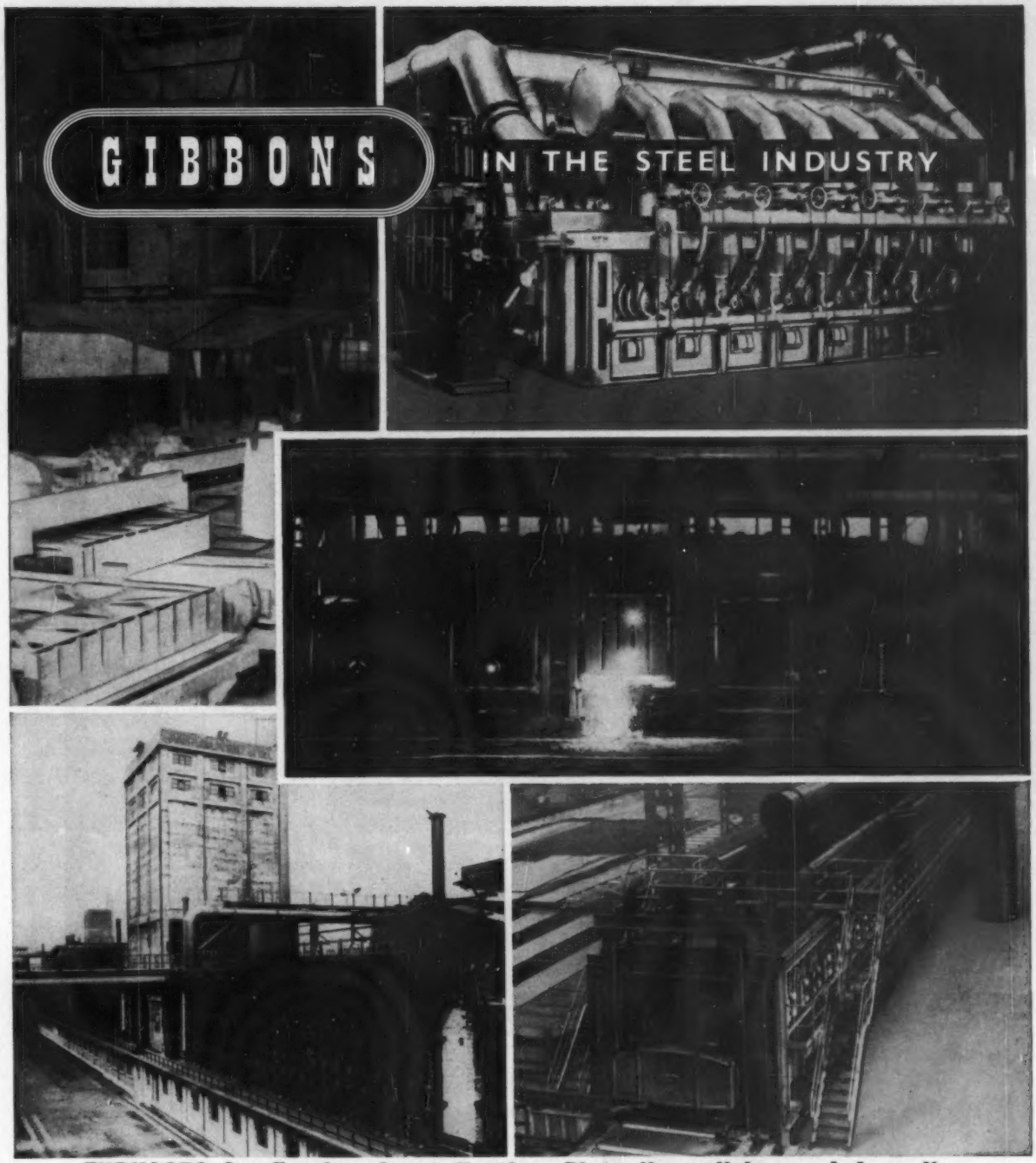

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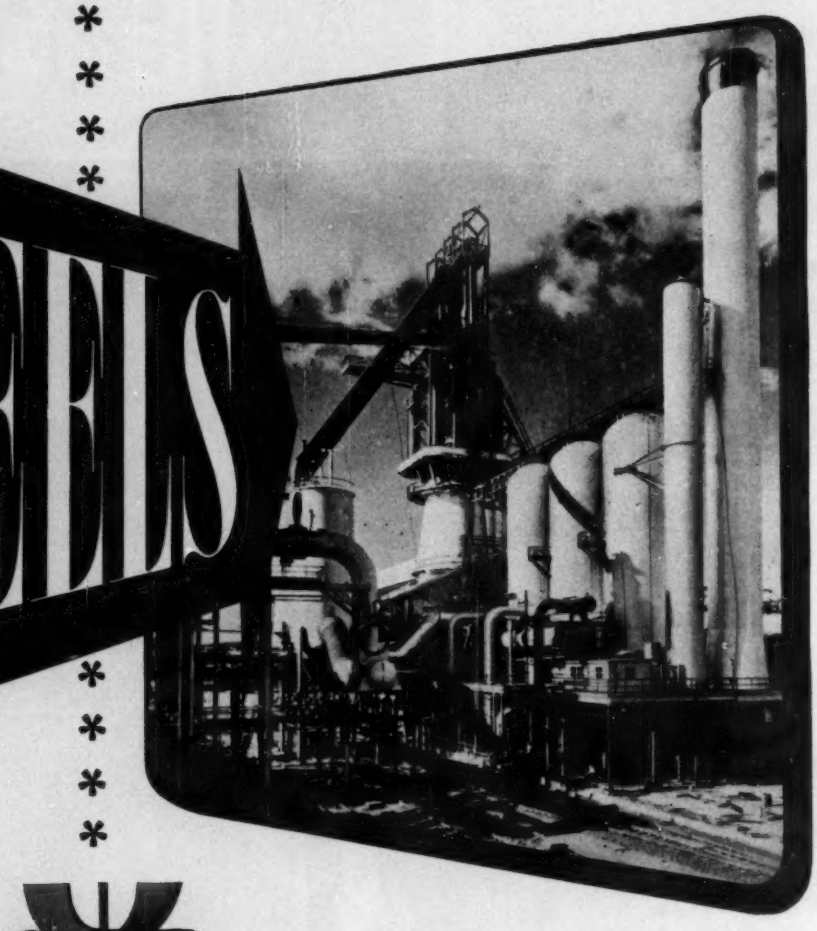

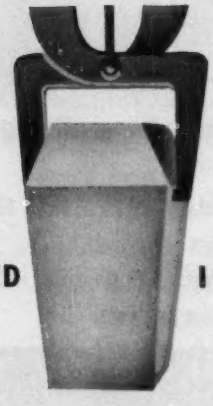

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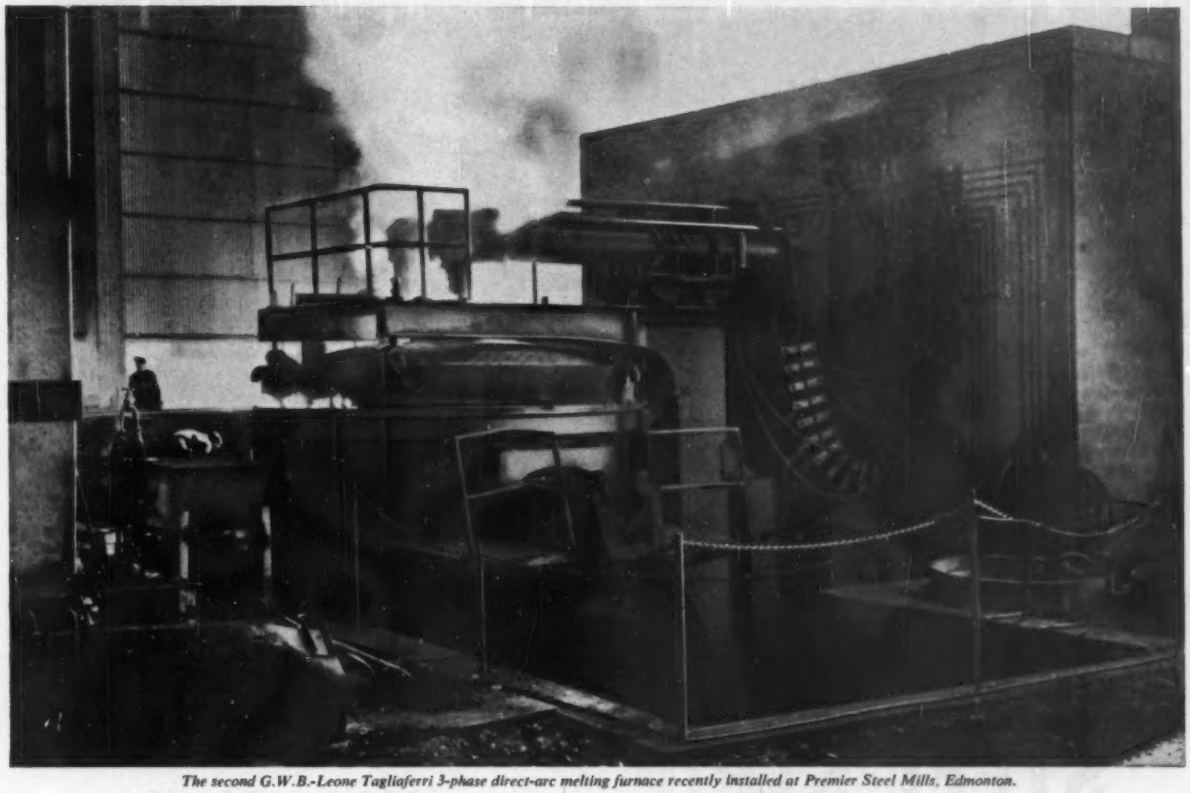
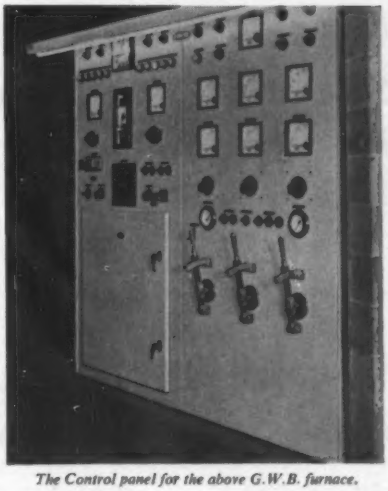
Outstanding performance of G.W.B. furnace leads to further Canadian order



The second G.W.B.-Leone Tagliaferri 3-phase direct-arc melting furnace recently installed at Premier Steel Mills, Edmonton.

A little over a year ago a G.W.B.-Leone Tagliaferri 3-phase, direct-arc melting furnace was installed at Premier Steel Mills Ltd., Edmonton—one of Canada's newest steel plants. The outstanding performance of this furnace, coupled with prompt delivery, led to an order for a second direct-arc melting furnace, which is now in operation and which has raised the mill's output to between 180-290 tons per 24 hrs.

Once again G.W.B. quality and service have been proved in practice. If you have a furnace problem why not contact us?



The Control panel for the above G.W.B. furnace.

SOME TECHNICAL DETAILS

The second G.W.B.-Leone Tagliaferri furnace—similar to the one installed in 1956, is a 3-phase, direct-arc melting furnace with a nominal capacity of 10 tons and an 11 foot shell. Rated at 4700 kVA it is designed for an output of 96 tons in 24 hours. (In practice it varies between 90-145 tons). Operation is hydraulic, by the Tagliaferri system which gives finer control and faster electrode operation.

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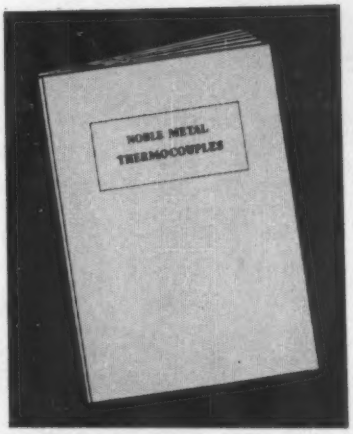
The measurement of molten steel temperatures

Modern developments in the production of improved and cleaner steels and of alloys for specialised purposes owe much to the use of the noble metal thermocouple—the most practical method of measuring high temperatures.

" Noble Metal Thermocouples " by H. E. Bennett, F.I.M., surveys the development of the noble metal couple and its uses in research and industry, with special reference to the steel industry. Copies are free on request.



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The slabbing mill motor room at Abbey Works

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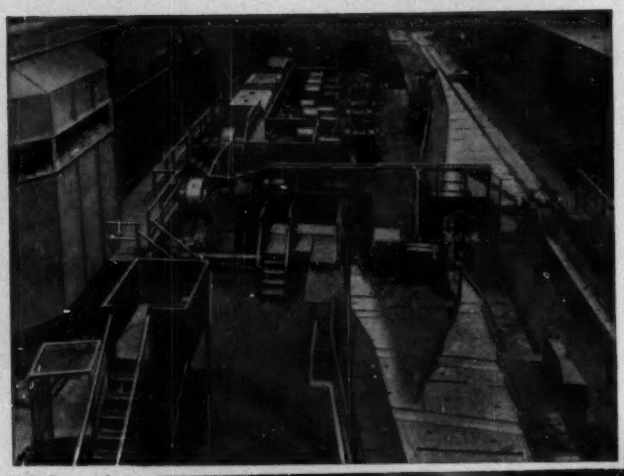

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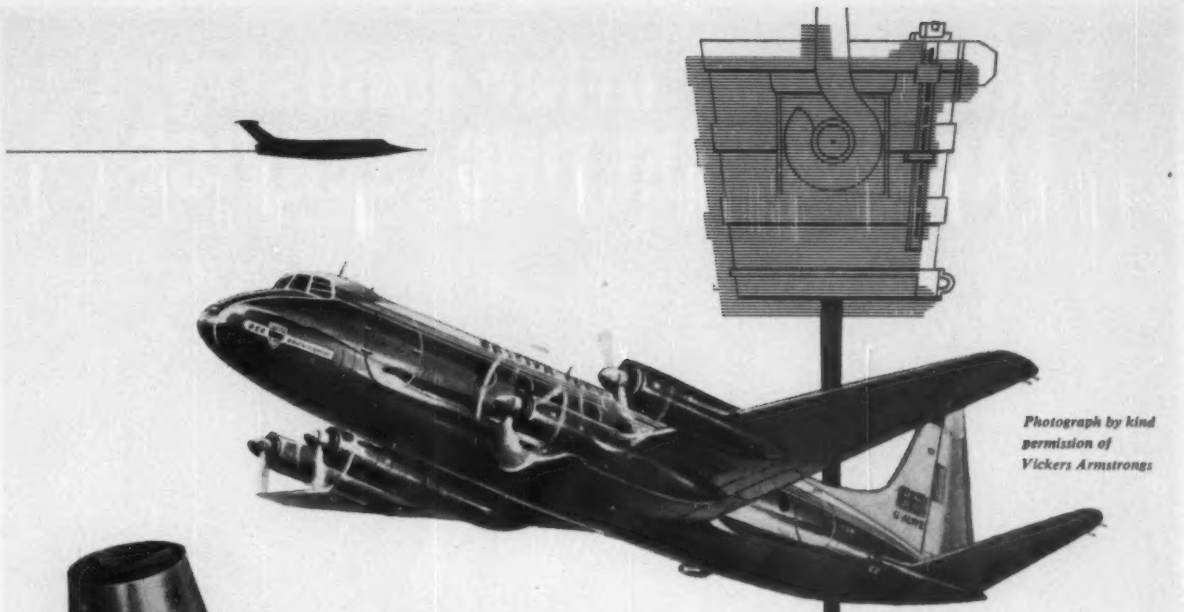

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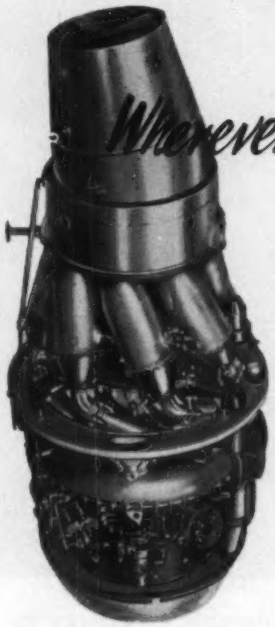
Wherever molten metals are being poured...



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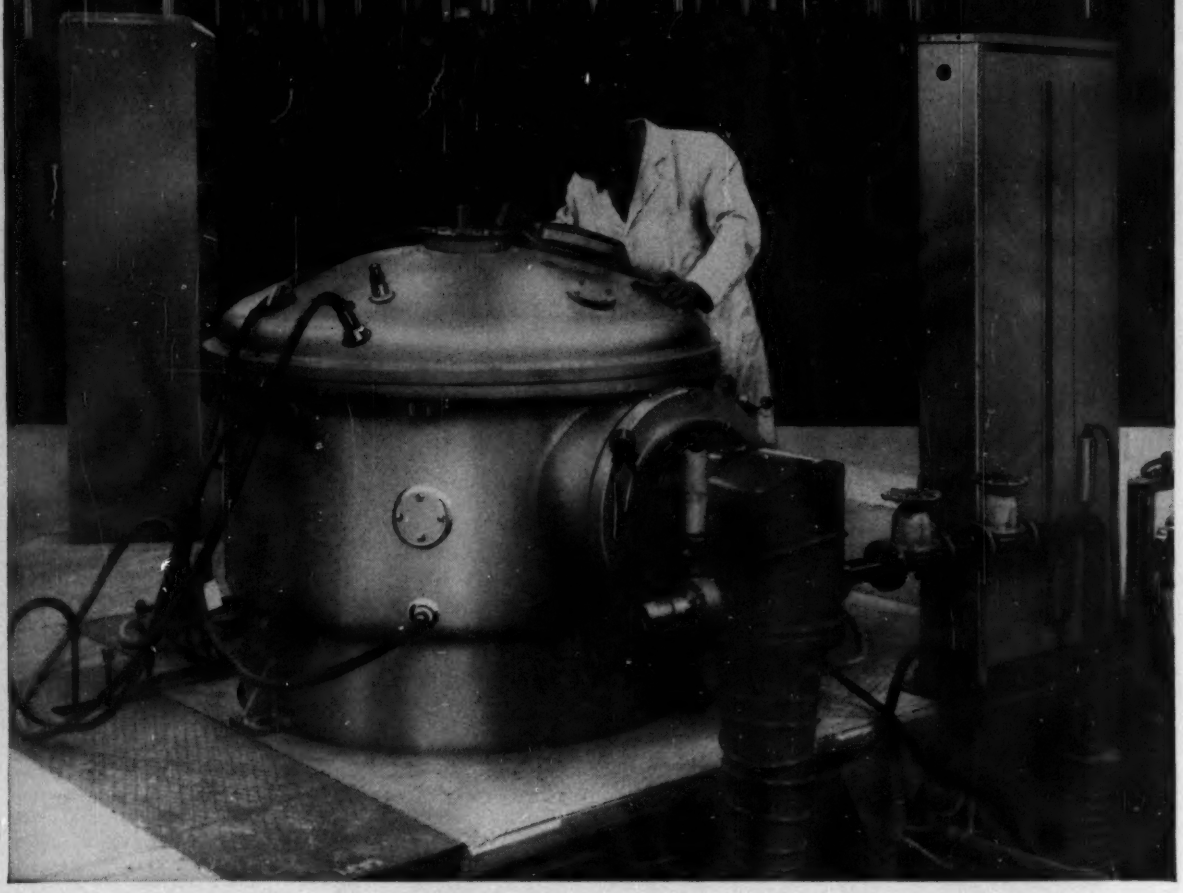

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Recent technical developments demand exceptional purity and very low gas content in alloy steels and melting under vacuum is proving to be the answer to the problems of producing such steels.

Willans have had considerable experience in making special alloy steels and they invite enquiries from metallurgical engineers who require such steels with specific properties. Vacuum melting may well prove to be the solution to their problems.

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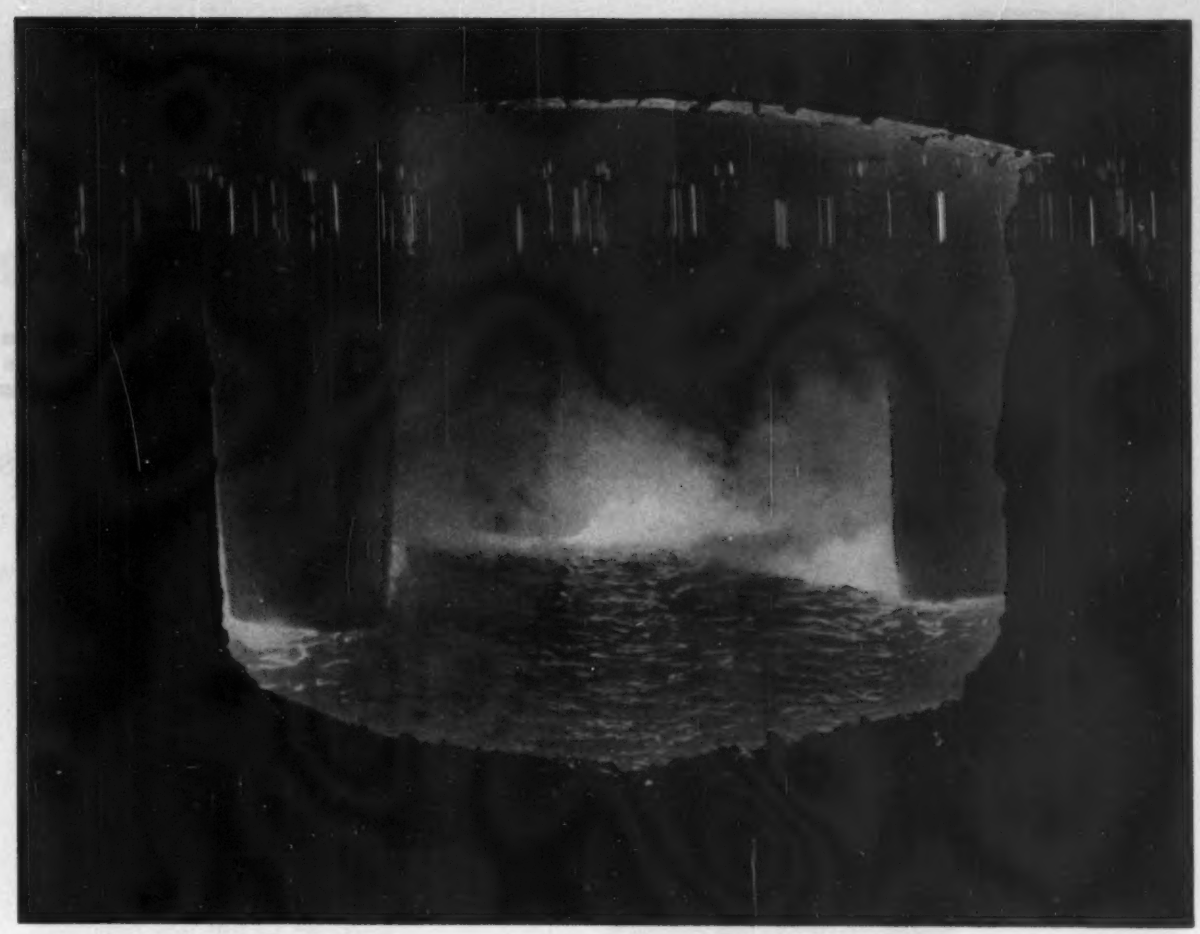

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Truly through its electrodes an arc furnace draws its breath of electric power. On the high quality and dependability of these lungs rests so much the burden of ensuring the smooth efficiency and economy of the arc furnace as a steel-melting unit. The excellent properties of "Acheson" graphite electrodes are a sure guarantee of first-rate performance

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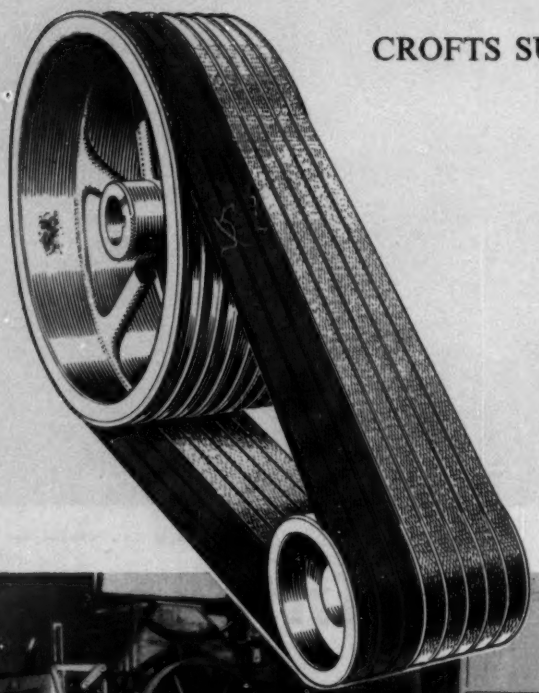

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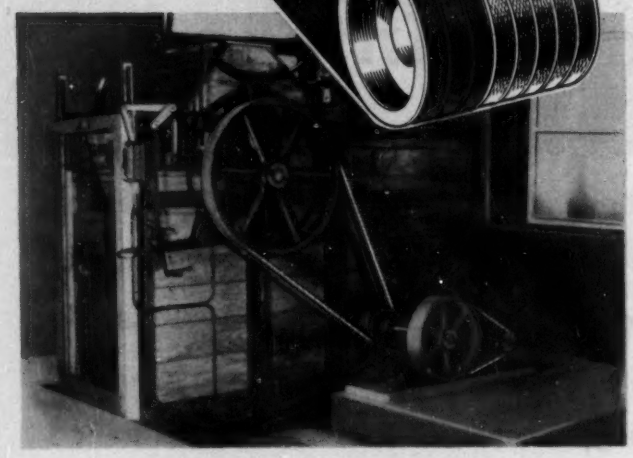

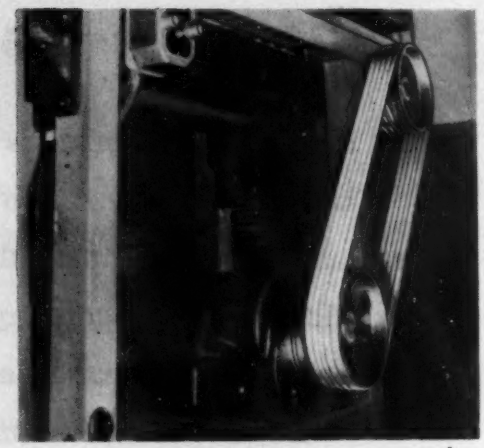

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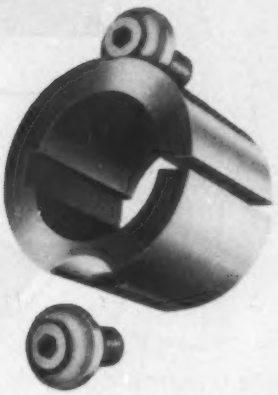

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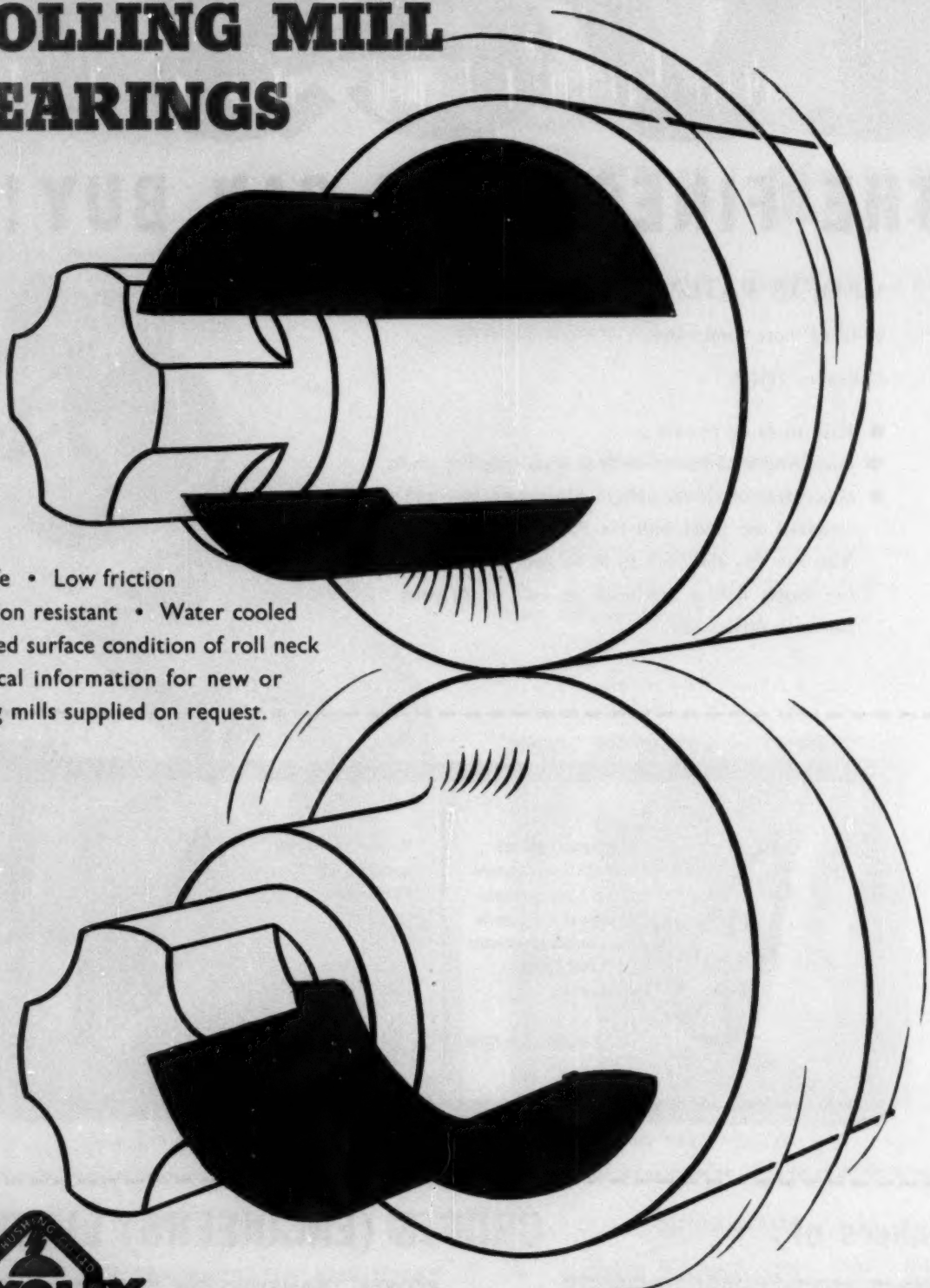

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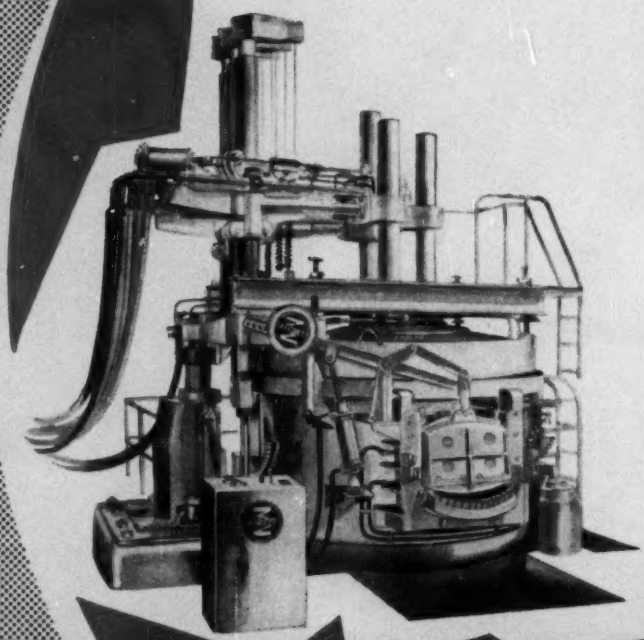

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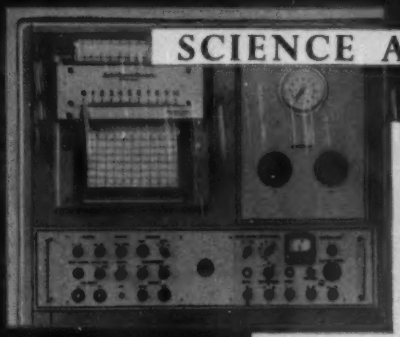

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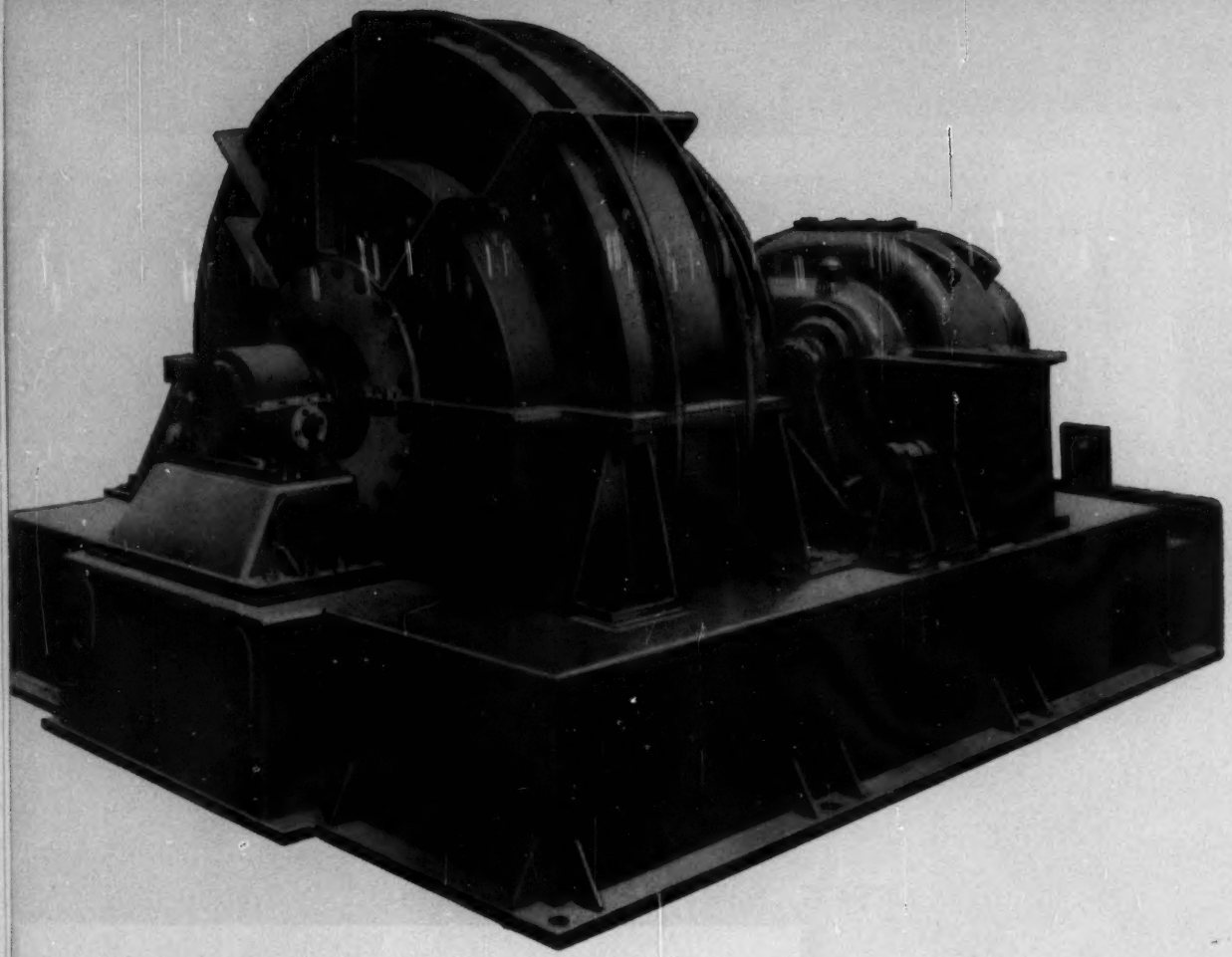

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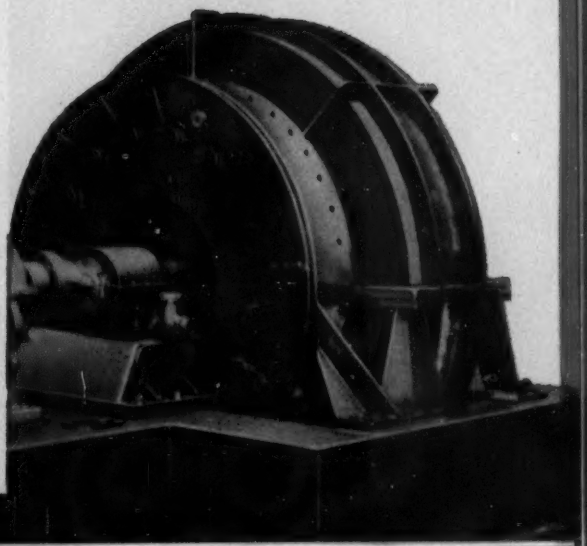

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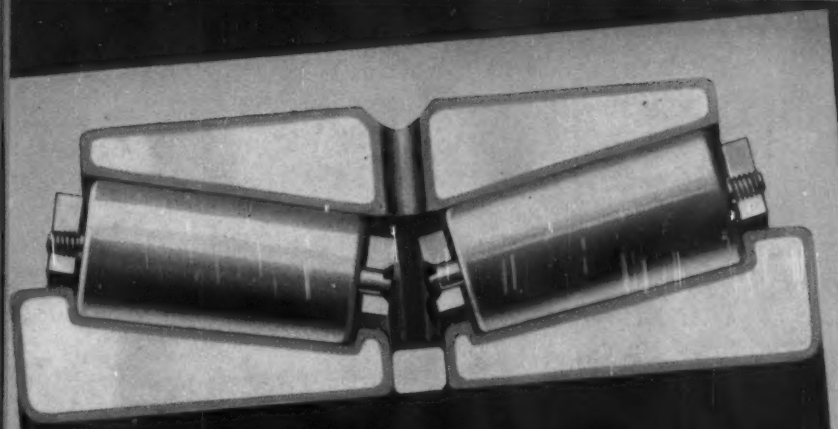

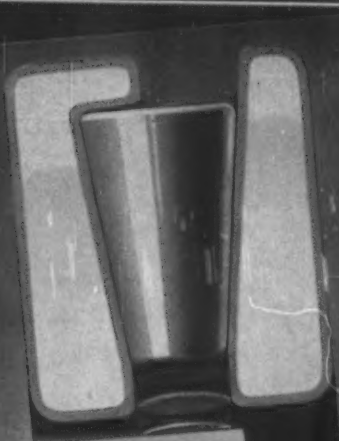

Not only on mill roll necks

Although the Timken tapered-roller bearings that we have shown on these pages have generally been those used on mill roll necks, these bearings are used extensively on ancillary equipment.

These illustrations show, half actual size, the following: *top left*, bearing for mill drive and pinion stands: *top right*, thrust bearing for screwdown breaker block: *bottom*, two-row heavy thrust bearing for reels, roller table line shafts and many other positions where thrust loads predominate.

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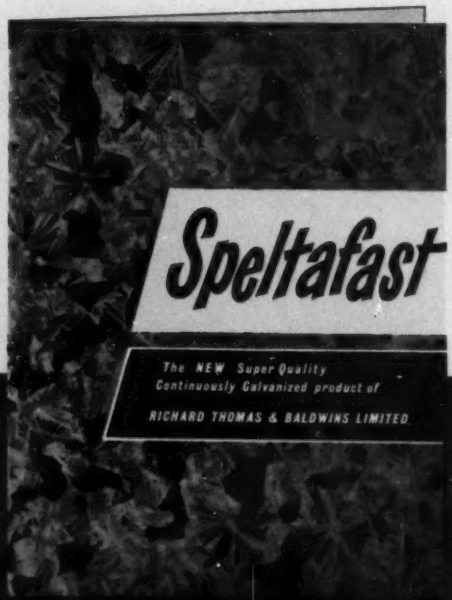

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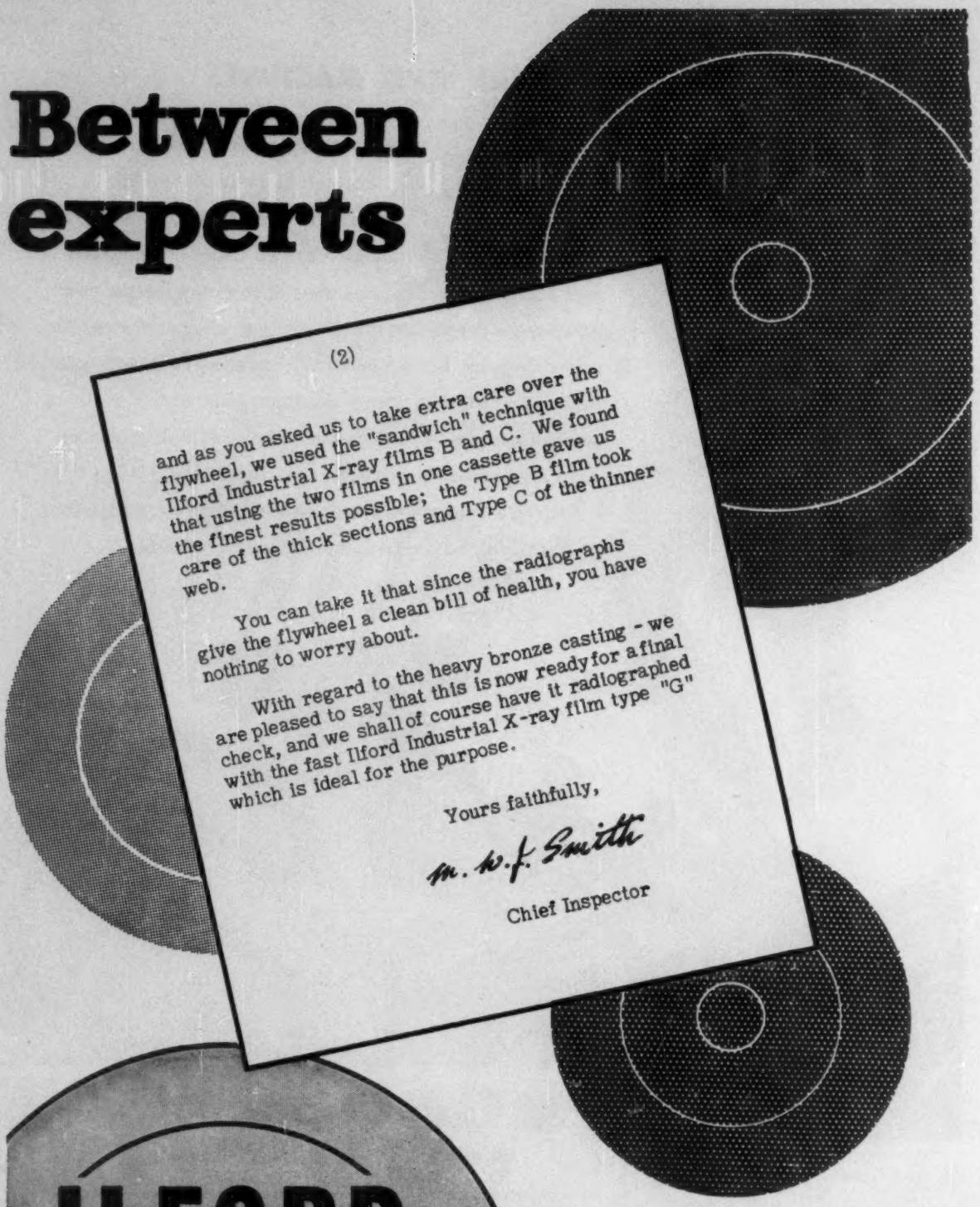
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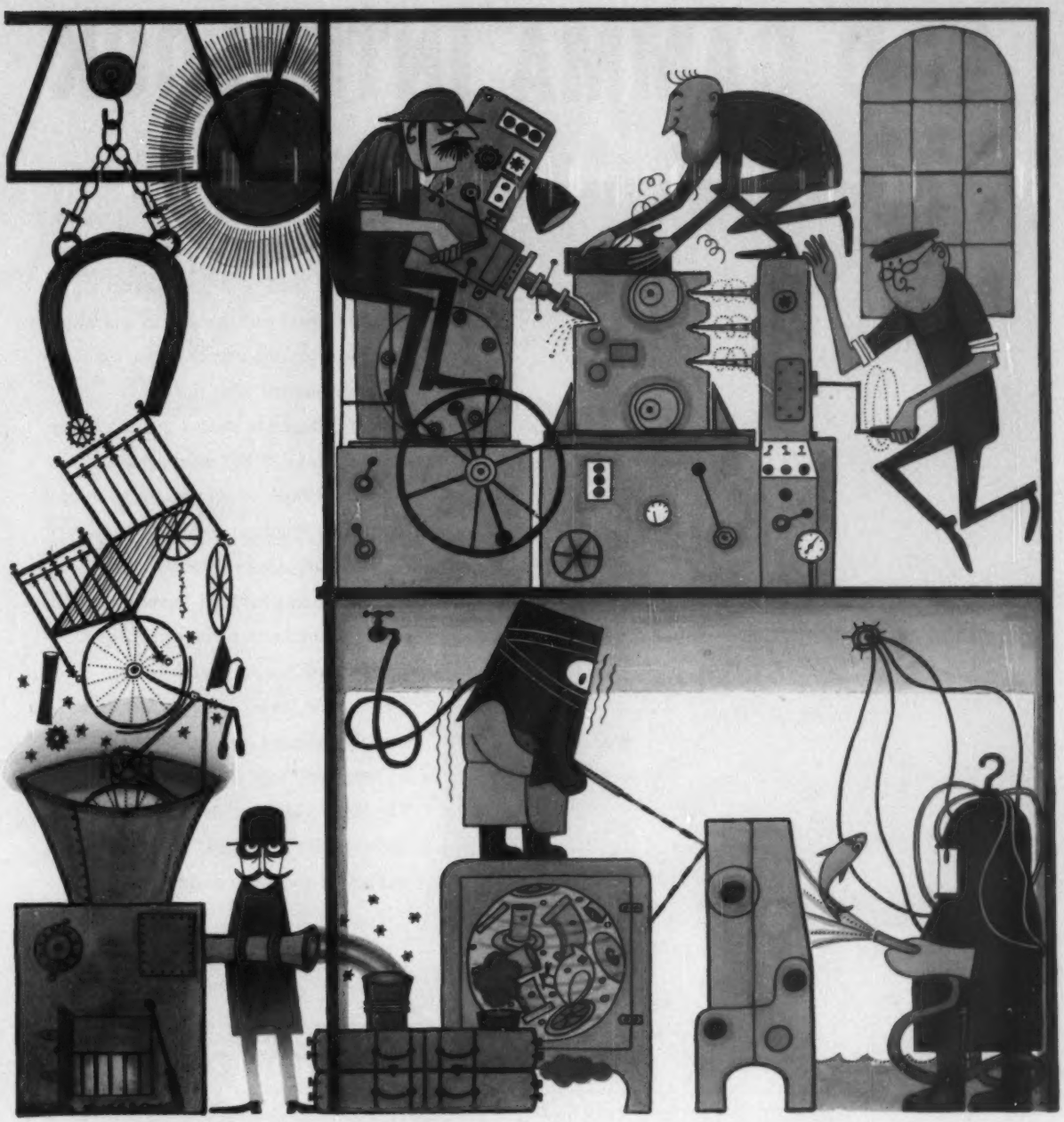

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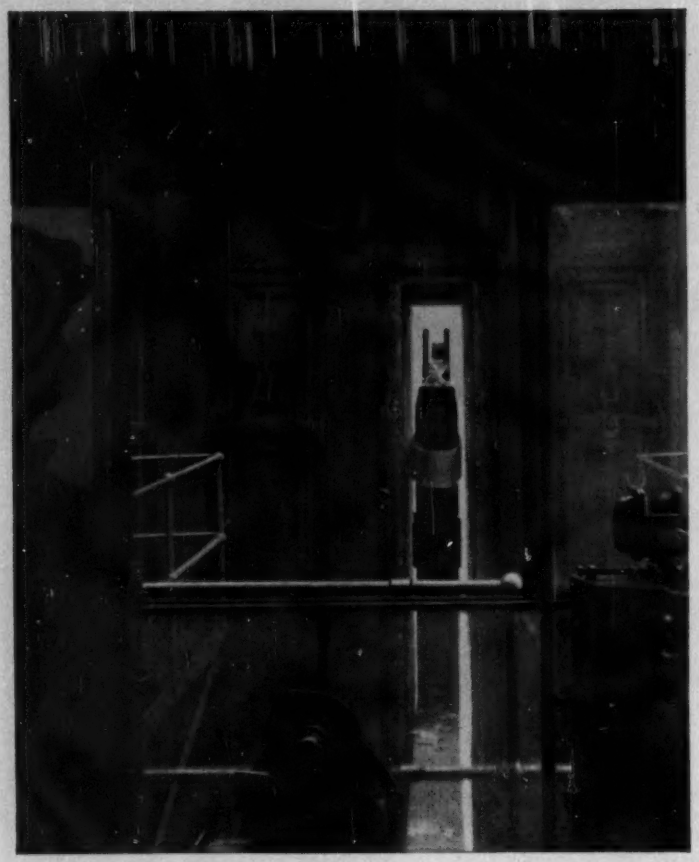

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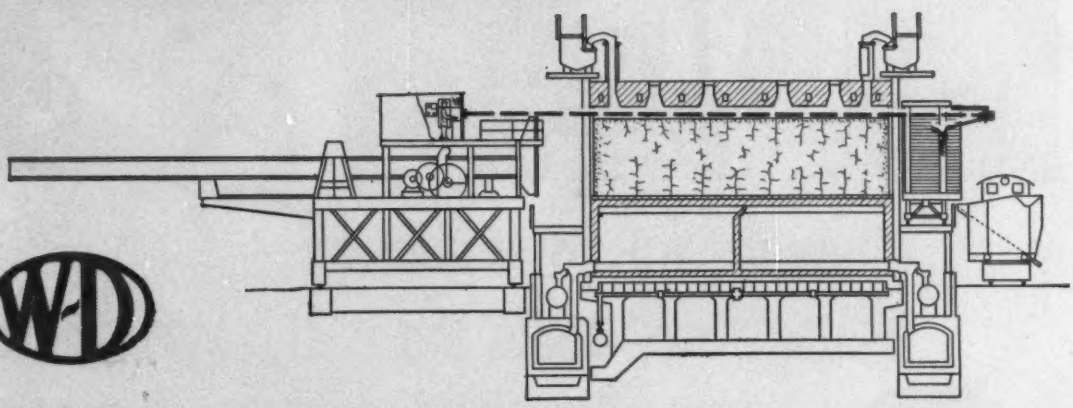

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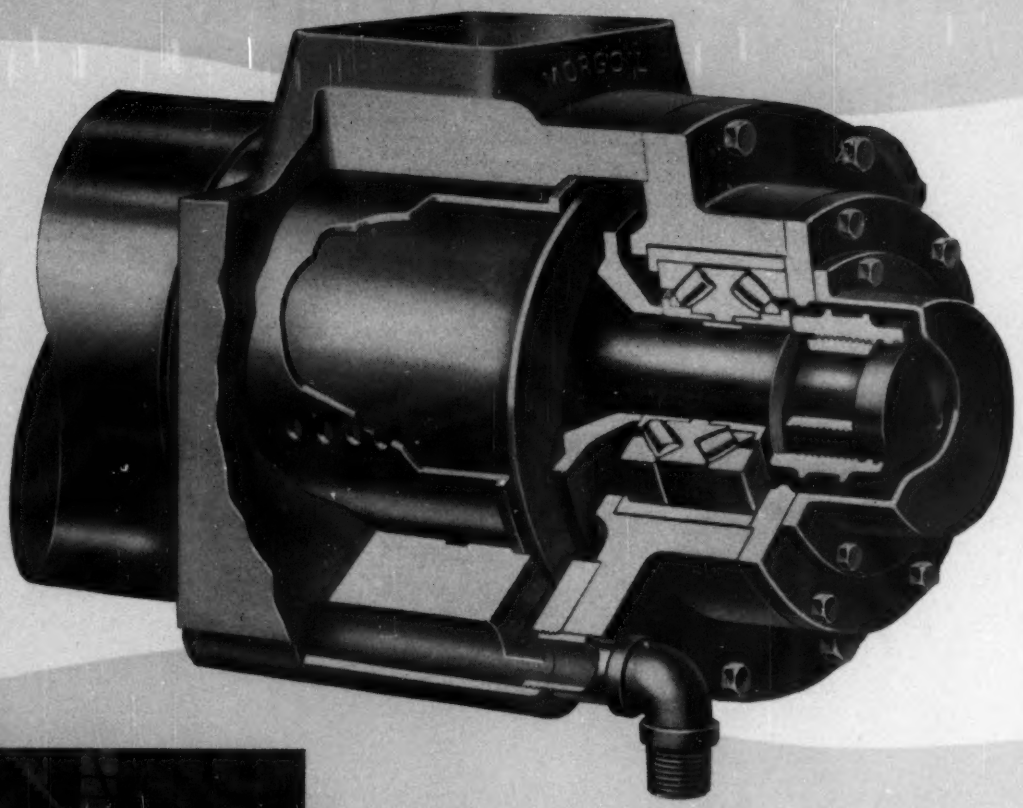

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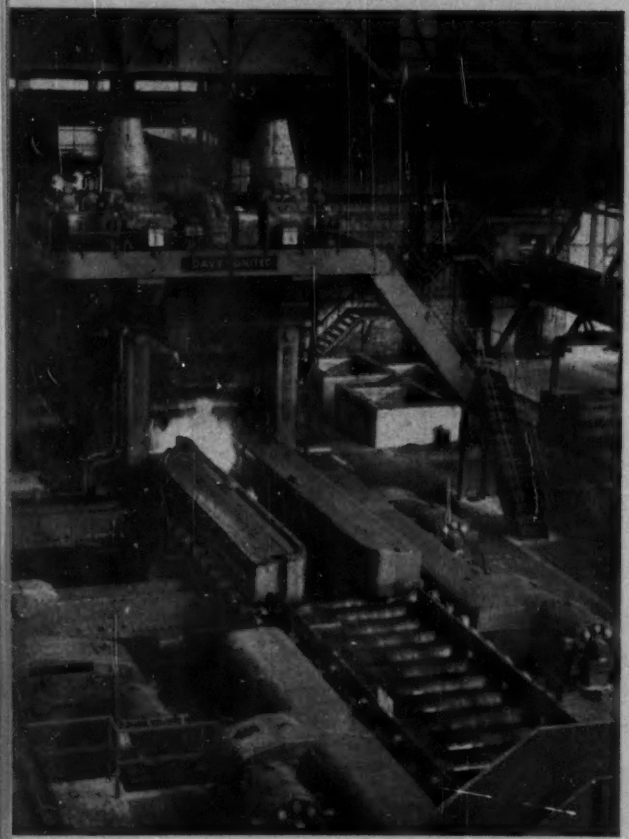

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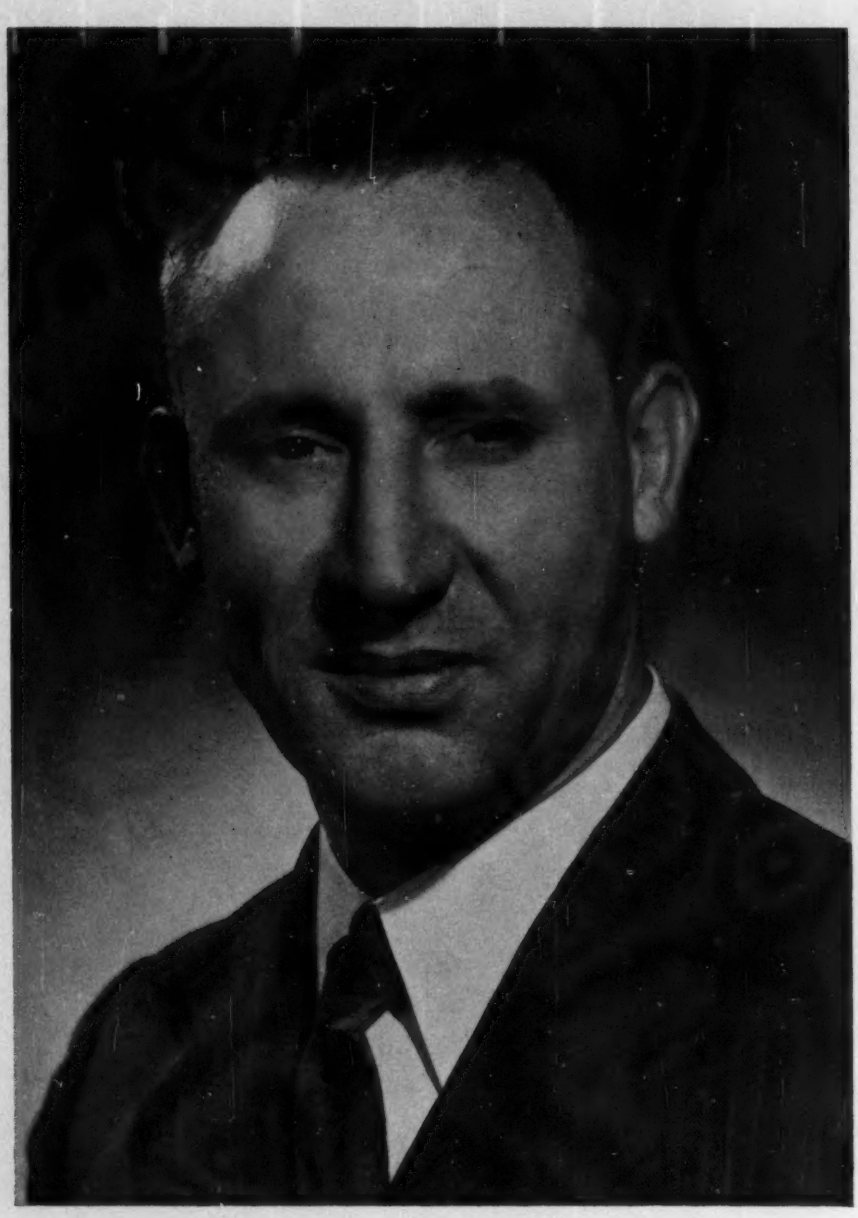
A. BIDDULPH, A.I.M.

ALBERT BIDDULPH was born at Altrincham in 1901, and educated at Bilston and the County Technical College, Wednesbury. After initial training as an engineer, he attended evening classes in metallurgy, and obtained the City and Guilds Certificate in Iron and Steel Production in 1929.

After serving an apprenticeship in engineering with the Sunbeam Motor Car Co., Ltd., he turned in 1923 to metal finishing, with the initiation of enamelling operations at Beech and Chambers Ltd., Birmingham, and technical control; in 1932, he left that company to become Production Manager at Vitreous Enamelling Co., Ltd., Birmingham. In the following year Mr. Biddulph became Superintendent of the Enamelling Department at R. & A. Main Ltd., Falkirk, and in 1938 he joined Ferro Enamels Ltd., as Technical Representative. On the outbreak of war he started a heat-treatment department for the latter company, and in 1941 was appointed their Technical Service Manager and Sales Manager.

Mr. Biddulph has been a member of the American Ceramic Society from 1929, and of the Institute of Vitreous Enamellers since its inception in 1934, being a member of its council from 1943, and Chairman from 1953 to 1955. He has presented many papers on the enamelling of iron, and has been closely associated with the educational activities of the I.V.E.

Mr. Biddulph joined the Staffordshire Iron and Steel Institute in 1929, becoming a Council Member in 1932, Vice-President in 1953, and President in 1956, and in the latter capacity served as an honorary member of the Council of The Iron and Steel Institute. He is an Associate of the Institution of Metallurgists.



A. Biddulph, A.I.M.

Honorary Member of Council, 1956–1957

PAPERS AND REPORTS ON RESEARCH AND PRACTICE

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The Nature of Strain-age Embrittlement

By C. J. Osborn, B.Met.E., Ph.D.

SYNOPSIS

The embrittlement which occurs in steel during ageing after plastic deformation can be studied conveniently by means of a notched-bar test, provided that the conditions of this test are carefully chosen and controlled. Curves showing the progress of embrittlement with time of ageing a low-carbon iron at 30° and 80° C closely resemble the corresponding strain-age hardening curves, and it is suggested that both embrittlement and hardening are due to the same basic process. It is shown that this proposal is not incompatible with the experimental results published by previous workers. The activation energy for strain-age embrittlement is calculated to be of the order of 20,000 cal/mole, which is the same as for strain-age hardening. 1436

IN MANY INSTANCES, the most important consequence of strain ageing in steels is a marked drop in the notched-bar impact value. However, Swinden[13] and others since have distinguished between this strain-age embrittlement and the strain-age hardening which produces changes in hardness, yield behaviour, electrical properties, etc. Since most investigations, including the theoretical treatments by Cottrell and his collaborators,[3] have dealt primarily with strain-age-hardening, any study of strain-age embrittlement must begin with a critical examination of the distinction drawn between these two aspects of strain ageing. If the distinction is real, there is urgent need for a thorough investigation of the embrittlement phenomenon. If, on the other hand, both processes are simply different manifestations of the same structural changes, an immense volume of data on strain-age hardening becomes significant in the study of strain-age-embrittlement. It is the purpose of this paper to present some evidence that this is actually the case.

EXPERIMENTAL

Transition Curves for Notch Brittleness

The notch-brittleness of mild steels has been demonstrated and investigated with a variety of physical tests and using a number of different criteria of brittleness. The results show that mild steels exhibit a sudden, severe embrittlement with decreasing temperature over a narrow transition-temperature range, which is usually somewhere between $\pm$ 100° C but which depends on both the test and the criterion of brittleness used. Furthermore, the transition range of a material measured by any particular test is known to vary appreciably with chemical composition and with its thermal and mechanical history. For example, the increase in notch-brittleness occurring during strain ageing is an indication that the transition-temperature range has been raised by the strain-ageing treatment, a phenomenon described first by Bolsover.[1]

However, there are obvious experimental difficulties in determining transition curves during the course of the strain-ageing process. One major difficulty arises from the necessity of machining notches in the test specimens after the straining operation. To determine a curve for 'as-strained' material, the notches must be machined promptly and quickly enough to avoid the occurrence of significant ageing between the straining and testing operations; and to determine the effect of ageing on the as-strained transition curve, controlled ageing treatments must be performed on machined specimens which are effectively in the as-strained condition at the start of the controlled ageing. The machining and handling problems introduced by the foregoing requirements are complicated still further by the fact that the establishment of a single transition curve requires a large number of test specimens.

Possibly because of the experimental problems involved, relatively few investigators have published transition curves showing the effect of strain ageing

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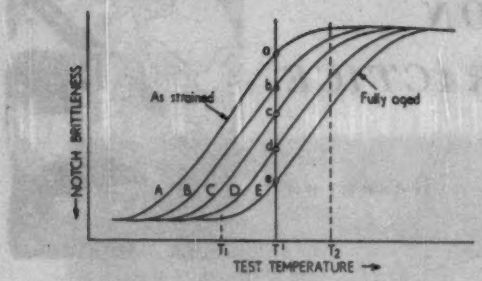

Fig. 1—Method of following strain-age embrittlement by testing at single temperature T'

on notch brittleness and only two have presented curves for freshly strained steels. Of the latter, Bolsover did not report the time elapsing between straining and notched-bar testing; and the present author and his co-workers[11] almost certainly allowed some strain ageing to occur in this period in their as-strained specimens.

Single Temperature Tests for Notch Brittleness

Because of the large amount of work involved in establishing complete transition curves for notch brittleness, many investigators have evaluated notch brittleness on the basis of tests performed at a single temperature, usually room temperature. However, it is found that displacement of the transition range to higher or lower temperatures does not necessarily affect the behaviour at temperatures remote from the transition range, and consequently single-temperature tests will only reflect changes in the transition temperature range when the testing temperature lies within the transition range. This means that, to use single-temperature tests to follow the effect of strain ageing on the notch-brittleness transition curve, the testing temperature must fall within the transition range of the material in both the freshly strained and fully aged conditions.

This is shown schematically in Fig. 1. If the transition curve A of a cold-worked steel changes with ageing through B, C, and D to the curve E for the fully aged material, it is suggested that tests should be conducted after various ageing times at a single temperature T', defined by $T_1 < T' < T_2$, where T_1 is the lower limit of the transition range in curve E and T_2 is the upper limit in curve A. The test results a, b, c, d, e, etc. obtained at T' will then describe the progress of ageing with increasing ageing times.

An inspection of Fig. 1 shows that this simplified procedure can only be used when the transition curve is sharply defined within the transition range, and when the transition range is wide enough to ensure that T_2, the upper limit of the transition-temperature range in the curve for freshly strained material, exceeds T_1, the lower limit of the transition range in the curve for fully aged material. Fortunately, these requirements are normally met by the common impact notch-brittleness tests. Furthermore, these are the only conditions which need be placed on the use of single-temperature tests to follow ageing. It is not necessary to have any further information regarding the shape of the transition curves, and these have been represented schematically in Fig. 1 as having the same shape.

Experimental Details

The material chosen for this work was a soft magnetic iron of the following composition:

		Composition, %			
C	*Mn*	*N*	*S*	*P*	*Si*
0·025	0·02	0·008	0·034	0·017	0·007

The factors which governed its choice were its known susceptibility to pronounced strain-age-hardening, its uniform ferritic microstructure, and its commercial availability.

The notch-brittleness test used in the present investigation was of the Izod type but it was found necessary to modify the shape of the notch. If the standard Izod test had been used, it would have required a testing temperature (T'' in Fig. 1) well above room temperature to follow the ageing as outlined above, and appreciable strain ageing could have occurred in the time necessary to bring the test specimens to the testing temperature.

To permit a testing temperature of 30° C to be used, a specimen was developed which gave lower transition temperature ranges than the standard Izod. It was essentially an Izod specimen with a notch of the usual depth (0·080 in.) but machined with a $\frac{1}{8}$-in. thick, $\frac{1}{16}$-in radius, convex milling cutter. The material was first machined to 0·404-in. square bars which were strained to 5% plastic elongation in a tensile-testing machine. These bars, which were then of standard 0·394-in. square section, were notched immediately, machining being completed about 10 min after straining. Part of the transition curve for specimens tested immediately after notching is given in Fig. 2. Testing temperatures were controlled by means of a vice similar to that described by Edwards.[5]

The ageing process was studied by transferring specimens direct from the milling machine to an ageing bath, where they were held for the desired ageing time and then tested at 30° C. Specimens aged at 30° C were tested immediately after removal from the ageing

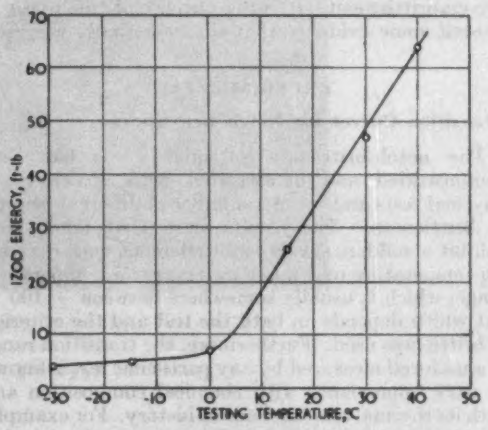

Fig. 2—Temperature/transition curve for freshly strained low-carbon iron, tested 10 min after straining; modified Izod test

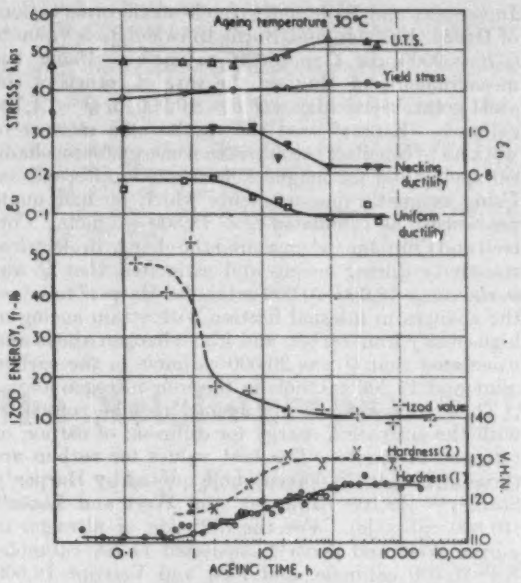

Fig. 3—Changes in mechanical properties of low-carbon iron during ageing at 30° C after 5% tensile strain

bath, while those aged at other temperatures were quenched to about 30° C and then held in the temperature-controlled Izod vice for 5 min before testing.

The changes in hardness and tensile properties of this material during strain ageing were also studied but the technique here was perfectly straightforward as all machining could be done before straining. The various tensile properties measured may be defined as follows:

If A_o = initial cross-sectional area, A_f = cross-sectional area at fracture, A_m = cross-sectional area at maximum load, U.T.S. = maximum load/A_o, Yield stress = lower yield point load/A_o

$$\epsilon_u \text{ (uniform ductility)} = \ln\frac{A_o}{A_m}$$

$$\epsilon_n \text{ (necking ductility)} = \ln\frac{A_m}{A_f}$$

RESULTS

The results of the strain-ageing experiments are

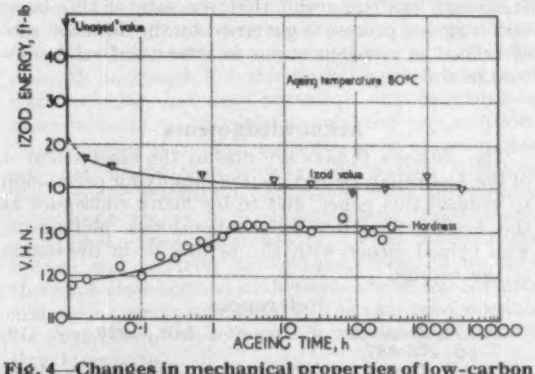

Fig. 4—Changes in mechanical properties of low-carbon iron during ageing at 80° C after 5% tensile strain

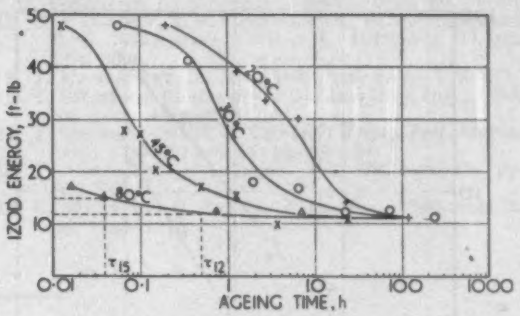

Fig. 5—Progress of embrittlement with ageing at various temperatures after straining 5%; modified Izod test

summarized in Figs. 3, 4, and 5. Figure 3 shows (from top to bottom) the results of tensile, modified Izod, and hardness tests after ageing at 30° C. The hardness curve *1* is for a single bar specimen, each point being the mean of six determinations, three on each side of two diametrically opposite faces. In hardness curve *2*, each point is the mean of three readings taken on an Izod specimen immediately before Izod testing.

Figure 4 shows the results of hardness and modified Izod tests after various ageing times at 80° C. Figure 5 presents results of the modified Izod test which show the rate of strain-age embrittlement at four different temperatures, 20°, 30°, 45°, and 80° C.

DISCUSSION

Comparison of Ageing Curves

With the low-carbon iron used in the present investigation it is evident from Fig. 3 that both strain-age hardening, including changes in tensile properties, and strain-age embrittlement reach completion after about 100 h at 30° C. Also, it seems probable from Fig. 4 that if the ageing is carried out at 80° C, both these processes reach completion after about 3 h. It is impossible to fix these times with any certainty, because of the gradually decreasing slope of the ageing curves as ageing approaches completion, but Figs. 3 and 4 show clearly that strain ageing is accompanied by simultaneous changes in hardness, strength, ductility, and notch brittleness, and that the ageing times necessary for these properties to reach constant, 'fully-aged' values are at least of the same order of magnitude.

It was pointed out in the introductory discussion that a distinction has frequently been made between strain-age hardening and strain-age embrittlement. This distinction probably arose from the work of Swinden[13, 14, 15] and Comstock,[2] both of whom reported examples of strain-age hardening for which no accompanying embrittlement was observed. However, it is significant that both of these investigators studied the effect of strain ageing on notch-brittleness at room temperature only, and in the absence of specific information to the contrary, it is not unreasonable to explain their results by assuming that the transition-temperature range of their steels was less than room temperature in both the aged and unaged conditions. Under these circumstances, strain ageing could cause an appreciable rise in the transition

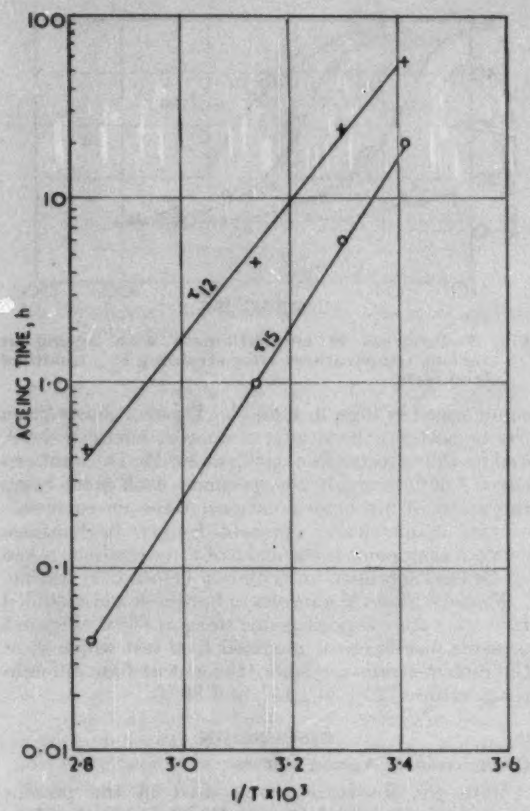

Fig. 6—Ageing time required for Izod energy to fall to 15 ft-lb (τ_{15}) and 12 ft-lb (τ_{12}) at various temperatures

temperature without any observable change in the room-temperature behaviour. Thus, while the results of these earlier investigators are probably not incompatible with those presented here, the interpretation that strain-age embrittlement and hardening are distinct phenomena is not justified by the early results.

Both the results in Figs. 3 and 4 and those of the earlier investigators appear to be consistent with the theory that strain-age hardening and strain-age embrittlement are simply different manifestations of the same fundamental process. Further evidence of this is obtained from a study of Fig. 5 and the calculation of activation energies.

Activation Energy for Strain-age Hardening

The temperature dependence of the rate of strain ageing may be expressed in the form

$$\tau^{-1} = A \cdot e^{-\frac{Q}{RT}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where τ is the time required for the hardness or some other property to reach a certain level, and Q is commonly referred to as the activation energy for the strain-ageing process. It has been shown that the activation energy for strain-age hardening is about the same as that for the diffusion of carbon and nitrogen in ferrite. This is consistent with Cottrell's theory.

Nabarro[10] used earlier hardness measurements of Davenport and Bain, and stretch–strain observations of Griffis, Kenyon, and Burns to calculate a value of $Q/R = 9000$, or $Q = 18000$ cal/mole. Using the measurements of Muir on the rate of return of the yield point, he calculated $Q/R = 10{,}900$, or $Q = 21{,}700$ cal/mole. Köster[9] used the results of a number of workers to calculate the activation energy for mechanical ageing and for magnetic and elastic after-effects. Using magnetic measurements which he had made previously, he calculated $Q = 18{,}800$ cal/mole. Cottrell and Churchman[4] measured the change in electrical resistivity during ageing and estimated that Q was in the range 18,000–20,000 cal/mole. Harper[7] followed the changes in internal friction with strain ageing of high-purity iron–carbon and iron–nitrogen alloys and calculated that Q was 20,000 cal/mole in the carbon alloy and 17,200 cal/mole in the iron–nitrogen alloy.

These values for strain ageing may be compared with the activation energy for diffusion of carbon or nitrogen in ferrite. The best values for carbon are those of Polder (18,000 cal/mole quoted by Harper[7]), Stanley[12] (18,100 cal/mole), and Wert and Zener[16] (19,800 cal/mole). For the diffusion of nitrogen in α-iron, Wert and Zener[16] calculated 17,700 cal/mole, Kê[8] 20,000 cal/mole, and Fast and Verrijp[6] 18,600 cal/mole. Within the limits imposed by experimental accuracy, the activation energies for strain ageing and for the diffusion of carbon and nitrogen in α-iron are in good agreement.

Activation Energy for Strain-age Embrittlement

Figure 5 shows the progress of ageing at 20°, 30°, 45°, and 80° C. It is not possible from these curves to determine with any accuracy the time at which ageing was complete, but a reasonable estimate can be made of the time (τ_{12}, τ_{15}) necessary for the modified Izod value to fall to some level such as 12 or 15 ft-lb. If these values of τ_{12} and τ_{15} are used for τ in equation (1), the activation energy Q may be calculated by the method of least squares to give $Q = 18{,}100$ cal/mole (using τ_{12}) or $Q = 23{,}100$ cal/mole (using τ_{15}). The results are presented graphically in Fig. 6.

Within the limits of experimental accuracy, these values of Q agree well with the activation energies quoted above for both strain ageing and the diffusion of carbon and nitrogen in α-iron. This agreement supports the belief that strain-age embrittlement is a manifestation of the same process as that involved in strain-age hardening and that the rate of this basic strain-ageing process is governed by the diffusion rate of carbon or nitrogen atoms in interstitial solid solution in the iron.

Acknowledgments

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The Metallography of Low-carbon Bainitic Steels

By K. J. Irvine, B.Sc., Ph.D., and F. B. Pickering, A.Met., A.I.M.

SYNOPSIS

A detailed study has been made of the metallography of low-carbon bainitic steels, as a result of which it has been possible to derive a relationship between tensile strength (or transformation temperature) and the structural features. It has also been possible to suggest a mechanism for bainite formation similar to that put forward by Cottrell and Ko.

At high temperatures close to the bainite transformation temperature (i.e. 600° C), the reaction starts by the formation of ferrite plates. These plates form by shear, are coherent, and grow slowly when carbon diffuses away from the ferrite/austenite interface. The ferrite plates merge to form large areas of ferrite and finally the carbon precipitates as bainitic carbide. The final microstructure therefore consists of areas of small bainitic ferrite plates surrounded by dense areas of large carbide particles.

At slightly lower temperatures (i.e. 500° C), the carbon cannot diffuse away so readily and is precipitated as large plates of carbide which allows ferrite plate growth to continue. The structure which is formed therefore consists of thin, elongated ferrite plates containing a fine dispersion of carbide particles.

With decreasing temperature (down to the M_S point at about 400° C), the ferrite plates' size decreases and the carbide particles become smaller and more evenly dispersed.

It is suggested that at high transformation temperatures the strength is due to the fine grain size of the bainitic ferrite structure but, as the transformation temperature decreases, there is an increased strengthening effect due to the dispersion of carbide particles.

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RECENTLY PUBLISHED WORK[1, 2] has shown that it is possible to obtain bainitic structures at air cooling rates in low-carbon steels by the addition of alloying elements to a ½% Mo–B base composition. It is possible to obtain tensile strengths between 40 and 80 tons/in² and thus the structures link up with low-carbon martensites. The mechanism by which boron imparts bainitic hardenability has already been discussed[1] but the extreme fineness of the microstructures has made their interpretation difficult. Optical microscopy shows that as the tensile strength increases the structure becomes finer and more acicular, but does not allow any quantitative measurements to be made to establish any relationship between structural features, such as grain size and carbide particle density and tensile strength. The greater resolution obtainable with an electron microscope makes such measurements possible and a detailed examination has now been made, using optical and electron microscopes. This shows that there is a close correlation between structural features and mechanical properties. It has also been possible to explain the way in which low-carbon bainitic structures form.

MICROSTRUCTURES OF LOW-CARBON BAINITIC STEELS

For this investigation representative steels covering the complete bainitic range were used and their analyses are given in Table I, together with the tensile strengths in the normalized condition. Over much of the tensile-strength range it is possible to resolve the microstructures with a real magnification of × 1500. For this magnification, Formvar replicas are suitable and, in fact, are preferred since direct carbon replicas are difficult to strip from the metal surface owing to the large carbides present. Formvar replicas were prepared and photographed at × 1500 and enlarged to × 4500 for analytical purposes.

At the lower end of the tensile-strength range (40–50 tons/in²), there is one grain-boundary system of a polygonal nature which is the prior austenite grain boundary, and another of much smaller dimensions, consisting of more elongated grains of bainitic ferrite.

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Dr. Irvine is Head of the Metallurgy Section and Mr. Pickering is Senior Metallographer in the Research and Development Department of the United Steel Companies Limited.

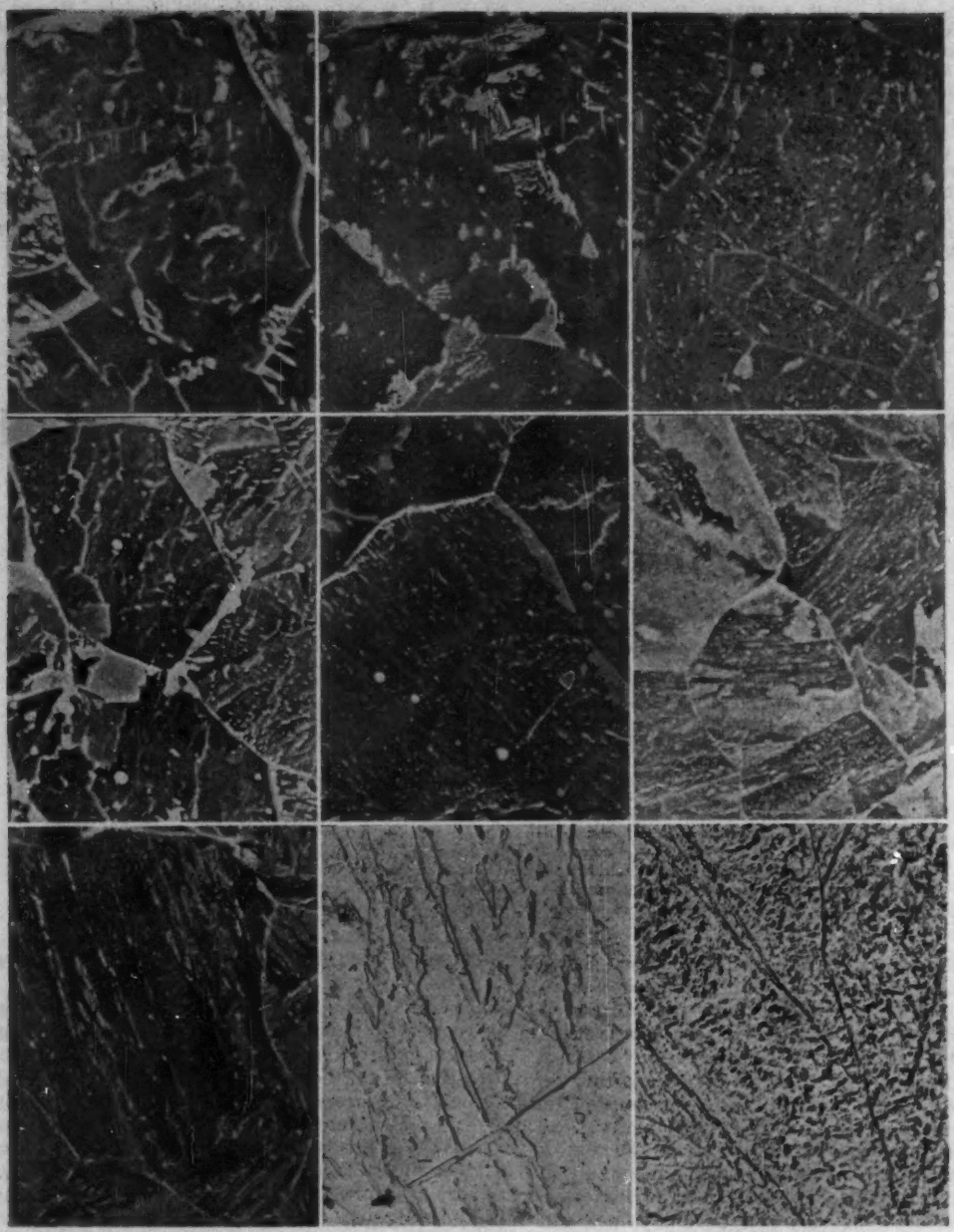


Fig. 1—Electron micrographs of bainitic steels *a–g* × 3000, *h–i* × 15,000

A structure of this type is shown in Fig. 1*a* and is typical of the bainitic steels referred to by Irvine *et al.*[1] Carbide is present not only at the austenite grain boundaries, and between the bainitic ferrite plates, but also as fairly dense areas containing very many carbide particles.

With increasing tensile strength, between 50 and 65 tons/in² (Figs. 1*b–d*), the grain size becomes smaller and there is a tendency for the grains to become elongated. The carbide particles become relatively small and form a fine dispersion within the grains, although there are still some present at the prior austenite grain boundaries. Figure 1*d* shows a very typical example of a high-strength bainitic steel. The change from the bainitic, 64 tons/in² steel to the martensitic, 88 tons/in² steel is shown in Figs. 1*d–g*

Table I

ANALYSES AND MECHANICAL PROPERTIES OF STEELS

Analysis Variable	Cast No.	Analysis, %						Tensile Strength in Normalized Condition, tons/in²
		C	Mn	Si	Cr	Mo	B (sol.)	
Cr	203	0·14	0·51	0·10	0·58	0·54	0·0017	49·1
	204	0·14	0·59	0·20	1·08	0·55	0·0019	64·2
	205	0·14	0·52	0·21	1·52	0·53	0·0015	69·1
	333	0·14	0·78	0·25	2·05	0·53	0·0027	76·9
Mn	210	0·15	0·85	0·17	...	0·54	0·0022	48·1
	211	0·17	1·42	0·21	...	0·52	0·0023	61·9
	330	0·15	1·90	0·24	...	0·50	0·0035	66·1
	331	0·14	2·95	0·29	...	0·55	0·0034	79·7
	332	0·15	4·00	0·28	...	0·55	0·0031	88·5
Mo	334	0·13	0·65	0·24	...	0·90	0·0035	50·5
	335	0·14	0·61	0·22	...	1·50	0·0024	54·6
	336	0·14	0·65	0·26	...	2·05	0·0020	59·6

The steels were made as 25-lb ingots, cast into approximately 4-in. square tapered ingots, and rolled to ¾-in. dia. bar. The normalizing temperature (Ac_3 + 30° C) was determined for each steel.

and it will be seen that even up to 80 tons/in² (Fig. 1*f*) the structure is still essentially bainitic.

In many high-strength bainitic structures, adjacent areas have different microstructures. In Fig. 1*e*, for instance, most of the structure is typical of a medium-strength bainitic steel, but the top left-hand grain has almost a martensitic appearance. This indicates a lower transformation temperature and it is probable that such areas have become richer in carbon owing to the formation of bainitic ferrite.

When using Formvar replicas taken from the highest-strength steels, it was also noticed that an extraction replica was obtained similar to that shown by Kuo[3] for a tempered steel. This was despite the fact that all replicas were dry-stripped, and presumably the effect was due to the very small particle size of the carbides.

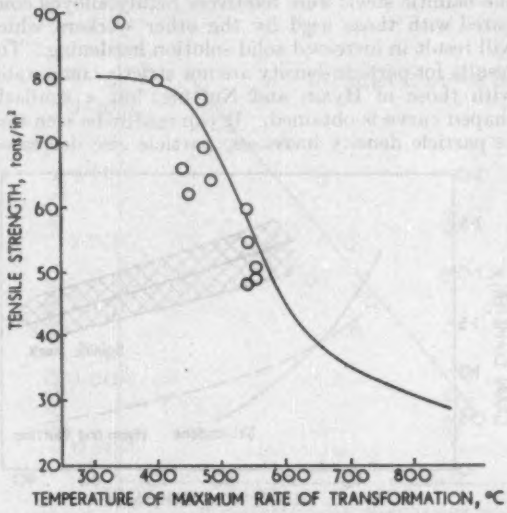


Fig. 2—Effect of transformation temperature on tensile strength

Figures 1*a–d* show that Formvar replicas and a magnification of × 3000 are adequate to resolve the structural features in the lower-strength steels. The higher-strength structures shown in Figs. 1*f* and 1*g* need greater resolution, however, and carbon extraction replicas have been examined. The microstructure of the 79 tons/in² steel is shown in Fig. 1*h*. Most of the structure is bainitic with the bainitic ferrite occurring as thin elongated plates. The structure of the highest-strength martensitic steel is shown in Fig. 1*i*. This consists of martensite, which has become auto-tempered owing to the high M_s temperature, resulting in the formation of Fe_3C as a Widmannstäten precipitate within each martensite needle or grain. This effect has been observed by Aborn[4] and the sizes of these cementite plates (2000 Å × 100 Å) agree well with those published by Aborn, who has commented that it is doubtful whether low-carbon martensite can form without self-tempering.

A clear distinction can thus be drawn between the low-temperature bainite and martensite, and it would appear that bainite plates are generally thinner than a martensite plate forming at approximately the same temperature. This can be explained by the fact that, unlike bainitic ferrite, the formation of a martensite plate does not require carbon diffusion and therefore rapid growth occurs until it is stopped by strain energy considerations.

Relationship between Structure and Tensile Strength

The two features of the microstructure which were measured were grain size and particle density. Quantitative measurements of grain size were made by the intercept method using a 10-cm datum line on the print. The particles counted were predominantly carbide particles but there was also a small number of martensite areas which were trapped between the bainitic ferrite plates. The density was assessed as the number of particles per square millimetre of the section; the results are given in Table II with tensile strengths and associated transformation temperatures.

Table II
ANALYSIS OF MICROSTRUCTURES

Cast No.	No. of Particles per Print	Density of Particles, no./mm³	No. of Grain Intercepts	Grain Diameter, μ	Tensile Strength, tons/in²	Transformation Temperature, °C
203	541	$1{\cdot}05 \times 10^6$	9·9	2·40	49·1	555
204	808	$1{\cdot}58 \times 10^6$	12·7	1·84	64·2	485
205	688	$1{\cdot}35 \times 10^6$	7·9	2·96	69·1	475
333	1024	$2{\cdot}00 \times 10^6$	12·4	1·82	76·9	470
210	340	$0{\cdot}68 \times 10^6$	10·3	2·21	48·1	540
211	1228	$2{\cdot}46 \times 10^6$	10·2	2·14	61·9	450
330	877	$1{\cdot}73 \times 10^6$	17·2	1·28	66·1	440
331	1566	$3{\cdot}07 \times 10^6$	13·4	1·64	79·7	400
332	1582	$3{\cdot}09 \times 10^6$	15·2	1·45	88·5	345
334	386	$0{\cdot}76 \times 10^6$	9·2	2·45	50·5	555
335	458	$0{\cdot}90 \times 10^6$	11·7	1·97	54·6	545
336	906	$1{\cdot}77 \times 10^6$	9·7	2·34	59·6	540

The effect of transformation temperature on the tensile strength of the steels used for this investigation is shown in Fig. 2. In this curve, the transformation temperature used is that for the maximum rate of transformation, which is obtained from the dilatation curve. The individual points fall close to the average line obtained from other work[2] and the scatter probably results from the variation in solid-solution hardening produced by the different amounts of alloying elements. This, in turn, produces some scatter in the structural relationship with tensile strength.

The relationship between the structural features and tensile strength is shown in Fig. 3; there is a close relationship with both grain size and particle density. As grain size decreases or as particle density increases, the tensile strength increases. It appears that both factors control tensile strength, but at the lower strength levels it is thought that grain size is the controlling factor because the carbide particles are mainly at the grain boundaries and in dense areas rather than generally dispersed.

As the tensile strength increases, however, dispersion hardening by the carbides becomes more effective, as shown by the increased slope in Fig. 3*b*.

A low-carbon Mo–B steel has been examined by Siriwardene[5] who showed that the hardness was a function of the grain size of the transformed product. A similar relationship has also been shown for quenched and tempered steels by Hyam and Nutting.[6] Figure 4 shows that when these grain-size relationships are compared with that obtained for bainitic steels, the latter have a higher tensile strength at any particular grain size. This is probably because the bainitic steels were relatively highly alloyed compared with those used by the other workers, which will result in increased solid-solution hardening. The results for particle density are not strictly comparable with those of Hyam and Nutting, but a similarly shaped curve is obtained. It can readily be seen that as particle density increases, particle size decreases.

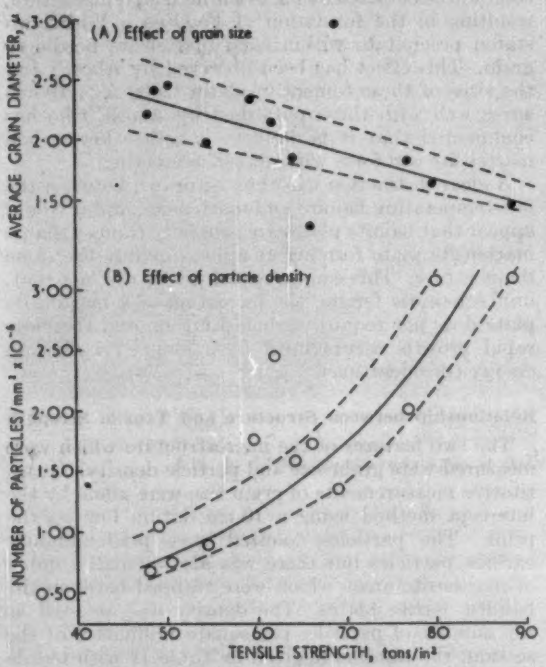


Fig. 3—Effect of microstructure on tensile strength

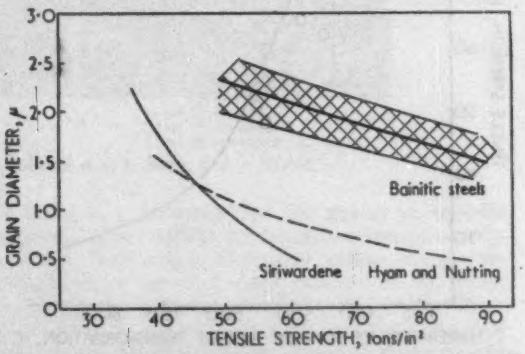


Fig. 4—Relationship between grain size and tensile strength

Table III
CHEMICAL COMPOSITION AND THERMAL DATA

Cast No.	Chemical Analysis, %						Thermal Data, °C			
	C	Mn	Si	Ni	Mo	B (sol.)	Ac_1	Ac_3	Normal Temp.	M_s
RM.443	0·15	0·60	0·20	1·00	0·51	0·0007	725	860	890	443
RM.444	0·16	0·59	0·19	1·57	0·52	0·0013	715	860	890	429

Relationship between Structure and Transformation Temperature

The relationships between grain size, particle density, and transformation temperature are shown in Fig. 5. Both curves show a clear relationship, with grain size decreasing and particle density increasing as the transformation temperature decreases. In fact, there is a better relationship with transformation temperature than with tensile strength, because variable solid-solution hardening introduces scatter into the tensile strength values.

Effect of Carbon Content

A point of interest in this study is the effect of carbon content. As particle density is one of the factors controlling strength, it is to be expected that carbon content will also have an effect. Steels covering a carbon content range of 0·05–0·20% have been examined, and it has been found that the effect of carbon follows logically from the relationship between tensile strength and particle density shown in Fig. 3*a*. At the lower end of the tensile strength range the carbide particles are mainly in dense areas at grain boundaries and have little effect on tensile strength. Consequently, there is little increase in tensile strength when the carbon content increases to 0·20%. As the tensile strength increases, however, dispersion hardening by the carbides becomes increasingly effective and therefore an increase in carbon content also produces more effect. It is very difficult to distinguish this as a separate effect, however, since carbon also has a marked effect in decreasing the transformation temperature. Further work is in progress to investigate medium-carbon bainitic steels.

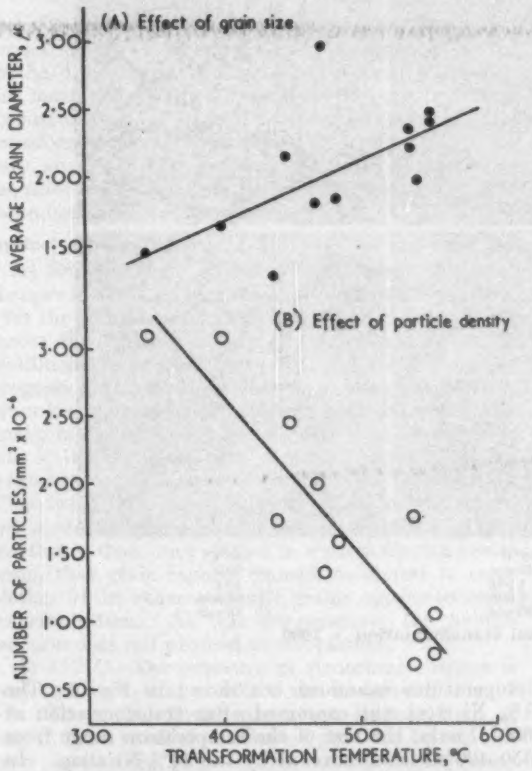


Fig. 5—Effect of transformation temperature

ISOTHERMAL TRANSFORMATION CHARACTERISTICS

Although the metallographic features of low-carbon bainitic steel have been described reasonably fully, it must be remembered that the structures described were all formed during continuous cooling and in many cases over a range of about 100° C. Much more information about the mechanism of this bainitic formation can be obtained from studies of isothermally transformed structures, as it is then possible to examine the progress of transformation.

The major requirement was that transformation should take place over as wide a temperature range as possible, and two steels were selected which fulfilled these requirements containing 1% and 1½% Ni added to a ½% Mo–B base. Full details of the analysis and thermal data are given in Table III. These steels transformed to bainite over the range 600–400° C, whilst on air cooling ¾-in. dia. bars the transformations took place over the range 515–435° C and 505–400° C, respectively. Both steels were therefore considered

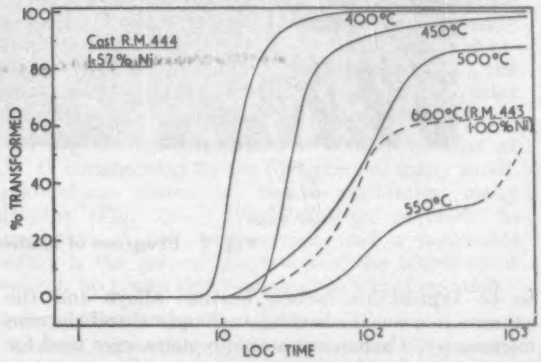
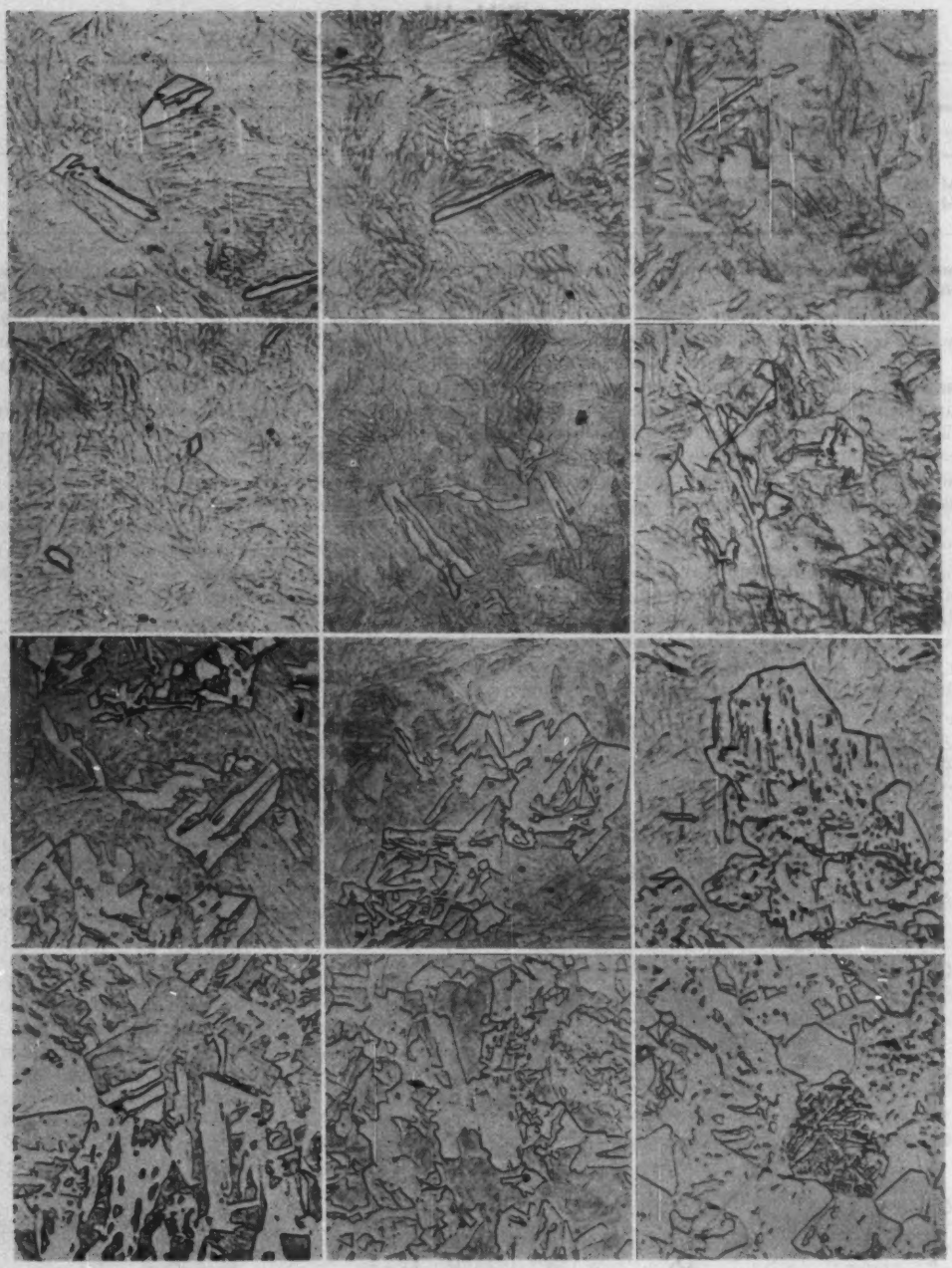


Fig. 6—Isothermal transformation curves at temperatures between 400° and 600° C



600° C
(*a*) 20 s
(*b*) 20 s
(*c*) 40 s
(*d*) 2 min

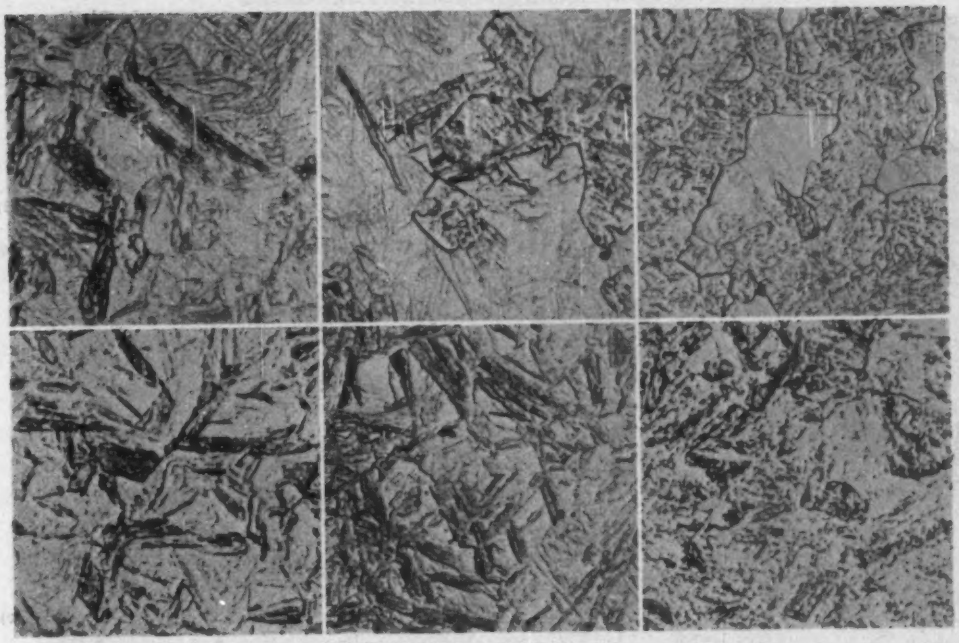
550° C
(*e*) 40 s
(*f*) 1 min
(*g*) 2 min
(*h*) 20 min

500° C
(*i*) 20 s
(*j*) 40 s
(*k*) 10 min
(*l*) 20 min

Fig. 7—Progress of isothermal transformation × 1000

to be typical low-carbon bainitic alloys and the examination was made using both optical and electron microscopy. Carbon extraction replicas were used for examination by electron microscope.

The transformation curves of the two steels at the temperatures examined are shown in Fig. 6. The 1% Ni steel was examined after transformation at 600° C only, the rest of the temperature range from 550–400° C being covered by the 1½% Ni alloy. In this steel the M_s point is calculated[7] at 429° C and



450° C (*m*) 20 s (*n*) 40 s (*o*) 4 min
400° C (*p*) 10 s (*q*) 20 s (*r*) 1 min

Fig. 7 (continued)—Progress of isothermal transformation × 1000

therefore it is estimated that some 20–30% martensite formed at 400° C before the bainite reaction. Owing to the difficulty in distinguishing optically between the martensite formed before the bainite and that formed during the quench to room temperature, the transformation curve shown in Fig. 6 refers to bainite only, and, as can be seen from the period of induction, the prior transformation to martensite has accelerated the subsequent bainite reaction.

Optical Microstructures

(*a*) *600° C*—The sequence of microstructural changes is shown in Figs. 7*a–d*. Transformation starts with the formation of small ferrite plates which grow across the whole austenite grain. These are often rectilinear in section (Fig. 7*b*). As transformation progresses, the ferrite plates form parallel growths, often trapping areas of austenite between them, and finally merge into large areas of ferrite extending over almost the whole austenite grain. The ferrite plates frequently exhibit several orientations (presumably all showing the same orientation relationship) within one austenite grain. A characteristic feature of this reaction is that, once started in a particular austenite grain, that grain rapidly transforms almost to completion whilst other austenite grains appear to resist transformation. At this temperature, the bainite reaction does not proceed to completion.

(*b*) *550° C*—The sequence of structural changes is very similar to that at 600° C and is shown in Figs. 7 *e–h*. The initial ferrite plates are thinner than at 600° C, form parallel or oriented growths, but do not grow into such large ferrite areas. Again some austenite grains are resistant to transformation, and, in general, there is more tendency for austenite to be entrapped between parallel growing ferrite plates (Fig. 7*g*).

(*c*) *500° C*—The microstructural changes are shown in Figs. 7 *i–l* and again the general sequence is the same. The initial ferrite plates are very thin and carbides can be seen to have formed between individual ferrite plates. As noted previously, once transformation has started within a grain, it rapidly goes to completion whilst other austenite grains are relatively resistant to transformation. The latter areas, however, do finally break down at this temperature into a series of very small ferrite plates (Fig. 7*l*).

(*d*) *450° C*—A notable difference in the transformation at this temperature (Fig. 7*m*) is that the first-formed ferrite plates contain very small carbide particles. The ferrite plates are very thin, and austenite entrapment between the growing plates is less evident. By the time transformation is complete (Fig. 7*o*), the structure bears little resemblance to the initial plates of ferrite, which can scarcely be distinguished.

(*e*) *400° C*—Transformation is similar to that at 450° C, commencing by the formation of many small, dark-etching plates of ferrite containing many carbides (Fig. 7*p*). Transformation proceeds to completion at this temperature, and a noticeable feature is the general dispersion of the transformed product, no grains being resistant to transformation.

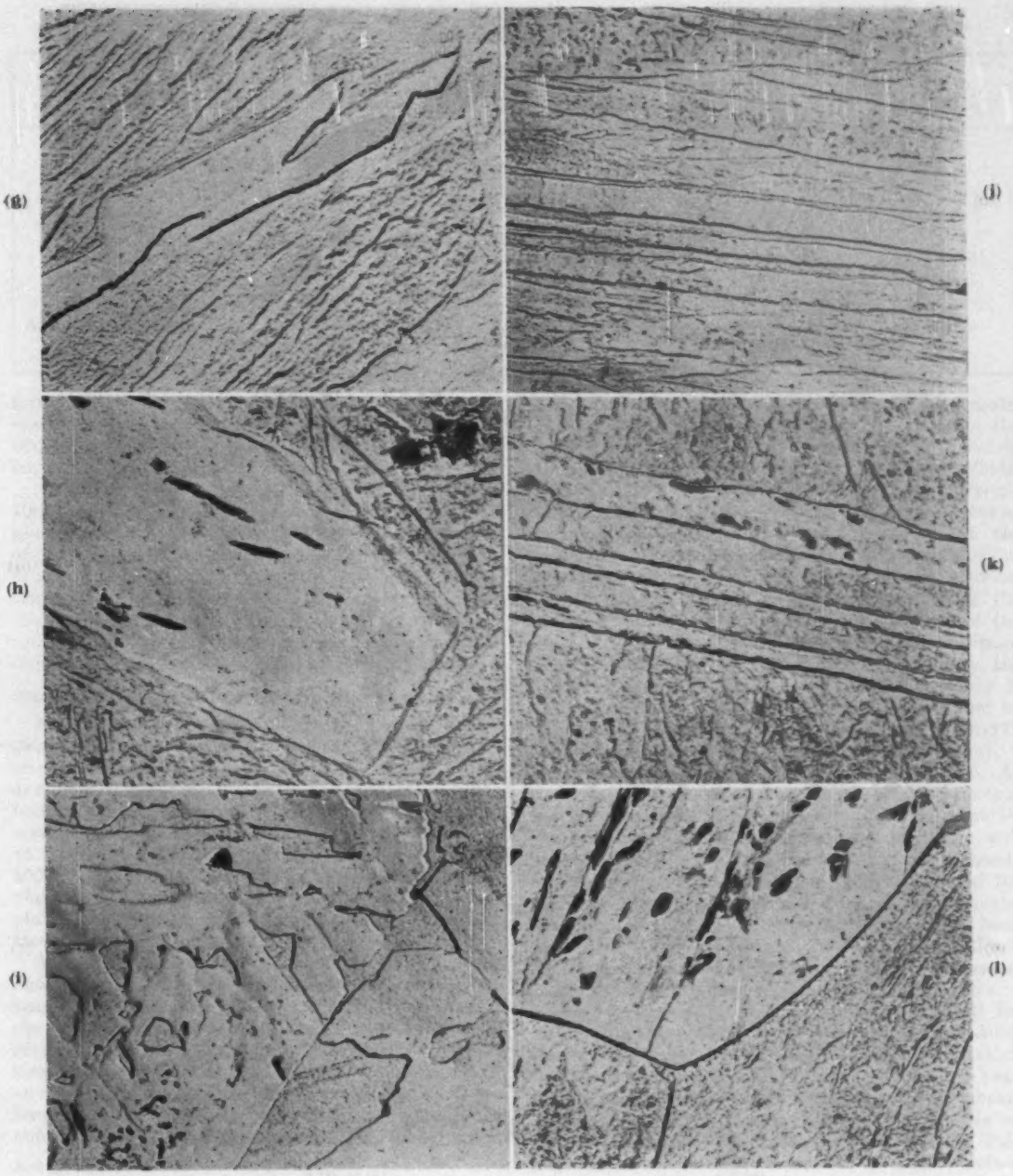
Electron Microscope Examination

Carbon extraction replicas were used to examine the structural features observed optically in more detail.

Fig. 8—Electron micrographs of isothermal transformation structures × 15,000

(*a*) *600° C*—The formation of ferrite plates at 600° C is shown in Figs. 8*a–c*. These plates are large and often nucleate at an austenite grain boundary, and Fig. 8*b* shows how austenite is trapped between growing ferrite plates which often extend across the whole austenite grain. The presence of a plate growing almost at right-angles to the section shown in Fig. 8*c* is clear evidence of the different orientations of ferrite possible within the general orientation relationship between austenite and bainitic ferrite.

(*b*) *550° C*—The structures shown in Figs. 8*d–f* show that the ferrite plates are finer and have a greater tendency to trap austenite between them. The austenite/ferrite interface shown in Fig. 8*f* is also



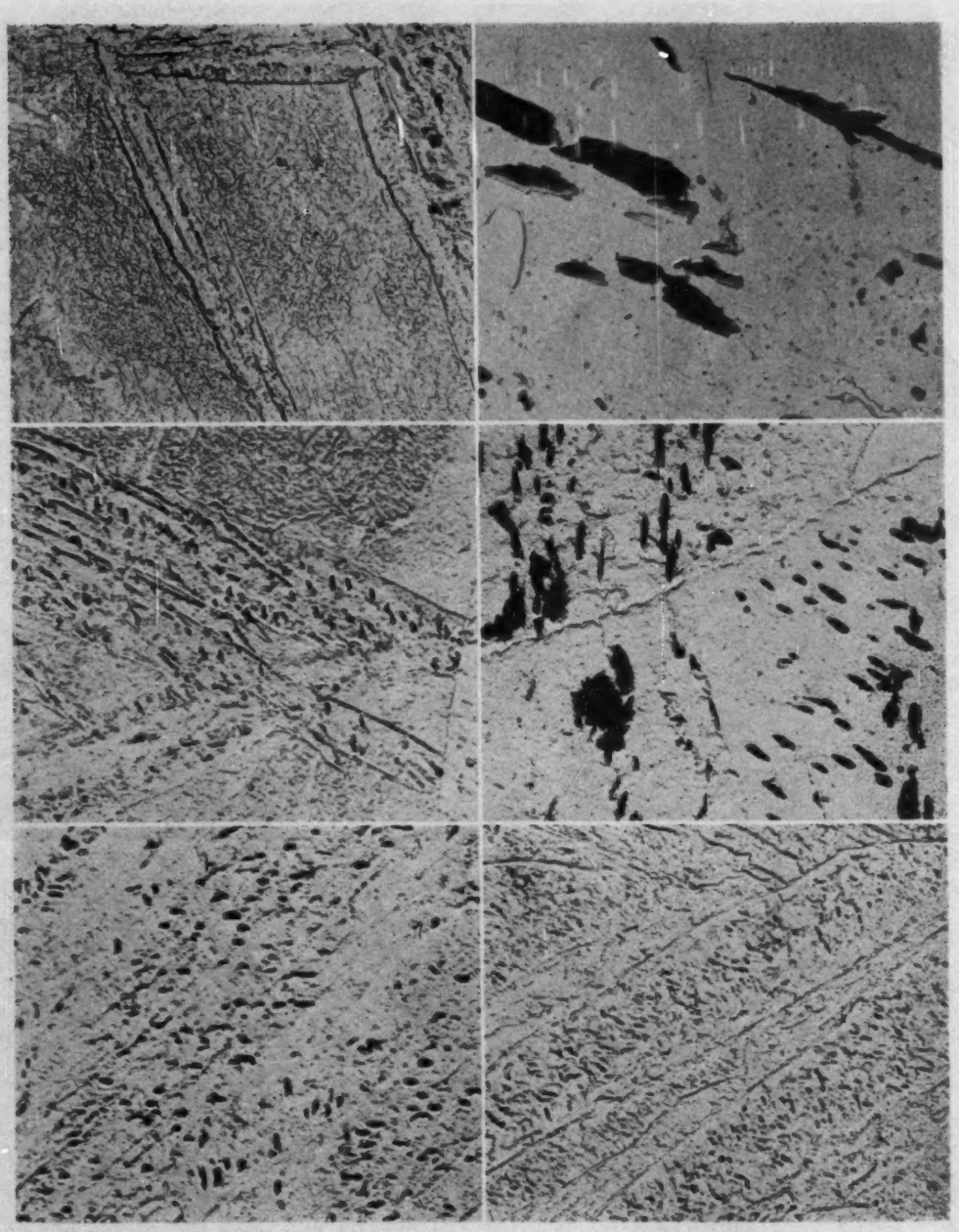
500° C
(*g*) 20 s
(*h*) 1 min
(*i*) 10 min

450° C
(*j*) 20 s
(*k*) 40 s
(*l*) 40 s

Fig. 8 (continued)—Electron micrographs of isothermal transformation structures × 15,000

interesting because there is a different structure of the martensite immediately adjacent to this surface, compared with the low-carbon martensite needles remote from the interface. This is probably due to a carbon concentration gradient at the interface produced by the bainitic ferrite formation. This will lower the M_s locally and prevent martensite needles growing up to the interface.

(*c*) *500° C*—The general progress of transformation at 500° C is shown in Figs. 8*g–i*. The ferrite plates are now very fine and form parallel growths which often extend across the whole austenite grain. The areas



400° C
(m) 10 s
(n) 20 s
(o) 40 s

Carbide particle size
(p) at 500° C
(q) at 450° C
(r) in low-carbon martensite

Fig. 8 (concluded)—Electron micrographs of isothermal transformation structures × 15,000

of trapped austenite break down to form plates of carbide, by what can only be considered to be a degenerate eutectoidal reaction. This probably accounts for the long plates or 'combs' of carbide often found in bainitic steels, and is in agreement with the optical structure (Fig. 7*k*) in which the dark etching carbide particles can be clearly seen between the bainitic ferrite plates. This effect is not seen above 500° C. The breakdown of the resistant austenite areas in Fig. 7*l* can be seen more clearly in Fig. 8*i*. This shows that carbide plates form in these areas, and probably indicates that this austenite has an increased carbon content.

(*d*) *450° C*—The structures in Figs. 8*j–l* show that thin ferrite plates form across the whole grain, but, before they have grown very wide, carbides begin to

Table IV
QUANTITATIVE MEASUREMENTS OF BAINITIC STRUCTURES

Transformation Temp., °C	Width of Bainite Plates when first formed, μ			Sizes of Carbide Particles, μ	
	Optical Microscope	Electron Microscope	Average	Length	Width
600	2·0	1·3	1·7	...	...
550	1·5	0·8	1·2	...	...
500	1·0	0·5	0·75	> 0·5	> 0·1
450	0·5	0·2	0·35	0·33	0·07–0·10
400	0·2	0·13	0·17	0·2	0·05
Auto-tempered martensite	...	...	≃1·0	0·1	0·02

form as plates within the bainitic ferrite. In many cases, parallel growths of ferrite plates are formed which merge to form areas of ferrite containing fairly large carbides, all oriented in the same direction.

(*e*) *400° C*—The progress of transformation at 400° C is shown in Figs. 8 *m–o*. The initial ferrite plates are very thin and as they grow carbide plates appear within the bainitic ferrite. These carbides are oriented with respect to the ferrite plate. Transformation proceeds rapidly and fairly uniformly to produce the structure shown in Fig. 8*o*, where carbide particles can be seen in a ferrite matrix. At this stage it is difficult to distinguish the individual ferrite plates.

Quantitative Measurements of Structural Constituents

The two main constituents are the bainitic ferrite plates and the carbides. As the transformation temperature decreases, the ferrite plates get thinner as shown by the results in Table IV. The length of the bainitic plates, however, remains fairly constant at a value equal to the original austenite grain diameter, at least down to a transformation temperature of 450° C. In general, the width of the lower-bainite plates is very much less than that of the martensite plates formed just below M_s, as previously reported by Howard and Cohen.[8]

At 500° C and below, carbide particles become observable and they get smaller as the transformation temperature decreases. The carbide particle sizes at the various transformation temperatures are also given in Table IV. Examples of the carbide particle sizes at 500°, 450°, and 400° C are shown in Figs. 8*o–r* and even the bainitic carbides formed at 400° C are large compared with the very small carbides in the auto-tempered martensite shown in Fig. 8*r*.

X-ray Examination

To examine whether carbon enrichment of the austenite during ferrite formation was sufficient to produce any retained austenite during quenching from the reaction temperature, X-ray side reflection photographs were obtained from polished and etched surfaces of suitable specimens. In no case was any retained austenite observed.

MECHANISM OF BAINITE FORMATION

There are two theories for the formation of bainite. Hultgren[9] postulated that bainite nucleates as a ferrite plate and grows as a ferrite–carbide aggregate. The growth of the ferrite creates conditions in the austenite at the γ/α interface such that the carbon content is sufficiently high to nucleate for carbide, which is then enveloped by the growing ferrite. Cottrell and Ko[10] suggested that bainite nucleates as ferrite by a shear transformation and that the growth of the coherent ferrite plate is diffusion-controlled, the free-energy change for the reaction being provided by the low carbon content of the ferrite. This is achieved either by diffusion of the carbon into the surrounding austenite, or by precipitation of carbides within the ferrite. Consequently, the bainite plate will stop growing when coherency is lost, when the carbon in the ferrite can no longer be reduced rapidly enough, or some obstacle to growth is encountered (e.g. an austenite grain boundary).

Both theories agree that the nucleus is ferrite. As the reaction temperature decreases, the critical nucleus size will also decrease and hence the number of nuclei (probably 'quenched-in' carbon fluctuations) will increase with decreasing temperature. This accounts for the decrease in minimum plate width and for the more uniform nature of the reaction as the reaction temperature decreases. It has also been suggested[11] that the bainite transformation will not be complete at high reaction temperatures because of the limited number of nuclei above critical size.

The present results suggest that the Cottrell–Ko mechanism is operative for low-carbon, low-alloy steels, and a general description of the transformation process can be given as follows. At temperatures near to B_s, bainitic ferrite plates form probably by shear, are coherent with the austenite, and grow slowly as the carbon diffuses away from the γ/α interface. This increase in carbon concentration at the interface slows down, and may even stop, the growth of the ferrite plate. These plates extend right across the austenite grain in which they nucleate, and the strain caused by the coherent growth appears to activate other nuclei, thus forming a series of parallel plates (Fig. 7*f*). Austenite is trapped between such plates (Figs. 8*a* and 8*c*) and becomes enriched in carbon: the neighbouring untransformed austenite grains also become richer in carbon. It is therefore less probable that these grains will transform, since the critical nucleus size will be increased (as postulated by

Hehemann and Troiano[11]), and also the carbon enrichment will be more pronounced at the austenite grain boundaries, thus neutralizing the most favourable nucleation sites. Local enrichment of this nature has been reported by Wever[12] and results in austenite grains which resist transformation.

At the higher transformation temperatures, the carbon can diffuse away fairly easily and the ferrite plates merge to form slabs of almost continuous ferrite over the whole austenite grain. At slightly lower temperatures, the carbon cannot diffuse away as already described and the trapped austenite appears to degenerate, forming large plates of carbide between the ferrite plates (Fig. 8*h*). This may account for the comb-like structure of some bainitic carbides in extraction replicas. The austenite grains, which are resistant to transformation, finally transform to a fine ferrite plate structure containing carbide precipitates (Fig. 8*i*).

With a further decrease in the reaction temperature, the rate of diffusion of carbon in austenite decreases and the growth of the ferrite plates is quickly stopped by carbon enrichment of the surrounding austenite (Fig. 8*m*). Carbide precipitation then occurs within the ferrite plates and the lowered carbon concentration in solution in the ferrite fulfils the thermodynamic condition necessary for continued growth of the bainite. The strain induced by the initial transformation causes neighbouring nuclei to be activated, so that transformation occurs rapidly throughout any individual austenite grain.

The change in the mechanism of the bainite reaction as the transformation temperature is lowered means that upper bainite is controlled by the diffusion of carbon in austenite, whilst lower bainite is controlled by the diffusion of carbon in ferrite. In the steels under consideration, this change occurs at 450–500° C but it can be predicted that in higher-carbon steels the change would occur at higher temperatures.

Recent work[13] has shown that the activation energy for the bainite reaction does change with temperature, being smaller for lower bainite than for upper bainite, although the values are rather lower than the published values for the activation energies for carbon diffusion ($Qc/\gamma \simeq 30{,}000$ cal/mole, $Qc/\alpha \simeq 20{,}000$ cal/mole). The low activation energies for bainite formation can be rationalized on the assumption that coherent growth demands arrays of dislocations at the interface and these would provide diffusion short-circuits and hence lower the activation energy.

When the structural features of bainite steels are considered it is not difficult to explain their strength. It must first be remembered that, under continuous cooling conditions, the transformation to low-carbon bainite often occurs over a range of more than 100° C. Consequently, the fully transformed structure consists of a mixture of different isothermal structures, and adjacent areas may have very different microstructures (Fig. 1*e*). Apart from the variation associated with the continuous cooling conditions, however, there is a very definite relationship between tensile strength and decreasing grain size in the upper bainite region, and between tensile strength and particle density in the lower bainite region. A typical medium-strength bainitic steel (Fig. 1*d*) results from a combination of fine grain size and the dispersion hardening effect of small carbide particles. This strength can only be lost by grain growth or carbide coalescence, which will only be produced by severe tempering treatments. Consequently, these bainitic steels are very resistant to tempering, and a study of the tempering characteristics will form the subject for future work.

SUMMARY

A quantitative examination has been made of the metallography of low-carbon bainitic steels and a relationship obtained between tensile strength or transformation temperature and the structural features. At high transformation temperatures (the lower tensile-strength level), the strength is largely controlled by grain size and, as the transformation temperature decreases, the grain size decreases and the tensile strength increases. At low transformation temperatures (the higher tensile-strength level), although grain size is very fine, there is an increasing strengthening effect due to the dispersion hardening effect of the carbide particles. Up to about 60 tons/in^2 tensile strength, carbon content has little effect on these relationships, but as carbon content increases particle density also increases slightly.

From a detailed examination of the isothermal transformation characteristics, a mechanism can be suggested for the formation of low-carbon bainitic structures which agrees closely with that put forward by Cottrell and Ko. The main feature of this reaction is that bainitic ferrite nucleates by a shear mechanism and carbon diffuses away from the growing ferrite plate. With decreasing reaction temperature, the rate of carbon diffusion limits the ferrite plate growth and the reaction can then only proceed by precipitation of carbide within the ferrite grains.

Acknowledgments

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The Electrolytic Migration of Carbon in Steels

By William Hume-Rothery

SYNOPSIS

Experiments on the electrolytic migration of carbon in steels are discussed. The view that carbon dissolved in austenite exists in the form of C^{4+} ions is criticized on the grounds of ionic radii and of the energies involved. It seems more probable that the carbon atoms are bound by forces resembling those of covalent linkages, and it is shown how this concept can be reconciled with the electrolytic migration data. 1479

EXPERIMENTS HAVE SHOWN that, when heavy currents are passed through wires or rods of steels at high temperatures, there is a migration of carbon in the direction which would be expected if the carbon atoms carried a positive charge. In the work of Dayal and Darken[1] the effect was examined at temperatures between 920° and 1220° C, and the results were claimed to indicate the presence of C^{4+} ions. This has been taken by some authors[2] to prove that, when in solution in austenite, carbon exists as C^{4+} ions. In the present note it is suggested that this conclusion is improbable, and an alternative interpretation is offered.

The carbon atoms in austenite are known to occupy the octahedral interstices in which each carbon atom is surrounded by six atoms of iron. The atomic radius of iron is 1·27Å, and the empirical crystal radius of the Fe^{2+} ion[3] is 0·75Å. The crystal ionic radius and the univalent ionic radius of the C^{4+} ion are only 0·15 and 0·29Å respectively.[3] In the crystal of austenite there is probably no sharp division between the atomic cores or ions and the bonding electrons, but the ionic radius of the C^{4+} ion appears to be too small for it to occupy the octahedral interstices.

The permanent existence of C^{4+} ions also appears to be improbable on account of the energies involved. The sum* of the first four ionization potentials of carbon is 147 V. This refers to the free atom, but, as iron atoms are not strong acceptors of electrons, it is difficult to imagine any conditions in the crystal lattice of austenite which would result in the stripping of four electrons from the carbon atoms.

The alternative view is that the carbon atoms in austenite are bound by forces resembling those of covalent linkages. In this case, since each carbon atom has six iron neighbours and only four valency electrons, the bonds will be fractional bonds of the type discussed by Rundle.[4] At the high temperatures employed by Dayal and Darken, the thermal motion of the atoms will tend to break the bonds, and at any instant a certain number of carbon atoms may be more or less unbound, and their bonding electrons transferred to adjacent parts of the crystal, where they will add to the negative charge of the carbon atoms. Under the influence of an electrical field, the carbon atoms which are temporarily positive ions may then be able to move as positive carriers owing to their small size. During their existence as positive carriers there will be compensating negatively charged carbon atoms, but these will not be able to move in the opposite direction because (*a*) they are still bound to their iron neighbours, and (*b*) a negatively charged carbon ion will be relatively large and will thus not move so freely through the lattice as a positively charged carbon ion.

If the above concept is correct, the carbon atoms in austenite are held by fractional bonds of a covalent type which tend to break down at high temperatures. The breaking of the fractional covalent bonds may produce some positively charged carbon atoms or ions, but these will be accompanied by corresponding negative ions, and the electrolytic experiments are such that, by their very nature, they reveal the positive but not the negative ions. It is thus incorrect to suggest that, taken as a whole, the carbon atoms in austenite are positively charged ions. It is to be noted also that the supposed agreement of the data of Dayal and Darken with the existence of carriers with a charge of + 4e was not conclusive. The agreement was obtained by omitting the result of one experiment which did not appear to confirm the remainder. Had this one experiment been included, the average of the whole series of six experiments would have indicated a charge more nearly equal to + 3e.

Manuscript received 4th September, 1957.

Dr. Hume-Rothery is Professor of Metallurgy in the University of Oxford.

* Thanks are due to Professor C. A. Coulson, F.R.S., for pointing this out.

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'Controlled Cooling' of Hot Ingots in a Single-ingot Pit at Appleby-Frodingham

By A. Jackson, N. H. Turner, and R. C. Walthew

SYNOPSIS

The first part of the paper reports on trials of a method of 'controlled cooling' individual hot ingots to render them fit for rolling. The second part discusses the application of this method to the normal run of casts.

Provided suitable integration of casting, transport, stripping, and charging can be obtained, the method described would permit the liberation of some of the fuel used in more conventional soaking pits. 1477

Introduction

INGOT HEAT CONSERVATION, which has been current practice at the Appleby-Frodingham Steel Company for many years, has emphasized the fact that a large proportion of ingots cast have still a heat content after stripping well in excess of that required for rolling.

Thus, the need of 'heating' such ingots in conventional live pits during the normal part of the week could be dispensed with, provided conditions were suitable. An investigation was therefore set afoot, the primary object being to ascertain whether such ingots could be satisfactorily conditioned or 'cooled' under control before rolling.

The ideal way would have been to have a sequence of charging and a heat content of the ingot charged such as would have permitted the heat content and temperatures of the pit at the end of the cooling period to be similar to those existing at the beginning of the period. As this would have been expecting too much under existing conditions, provision was made for an independent heat supply to the trial pit, to be used when required.

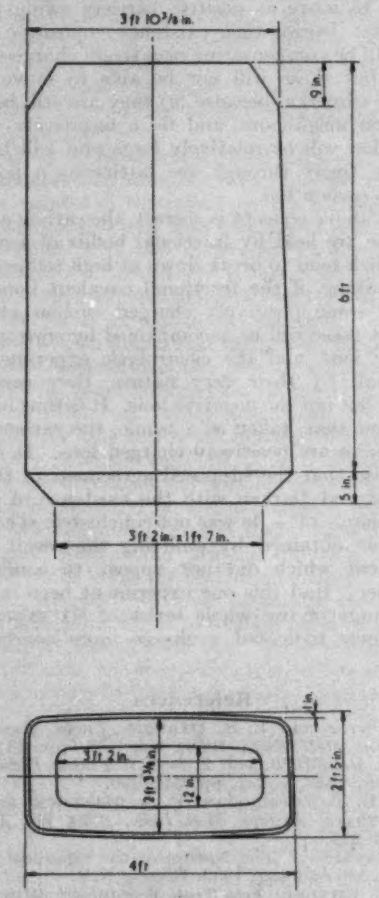

Fig. 1—10-ton ingot

PRACTICAL TRIALS

Ingot Data

The following data appertain to the ingots charged:

Nominal weight	10 tons
Dimensions	As per Fig. 1
Average steel quality: Balanced steel	0·10–0·24%C
Mould/ingot weight ratio	9·45 tons 10·2 tons
Average mould temperature at start of teeming	75° C
Average tapping temperature	1587° C

Pit Installation

The experimental pit (*see* Fig. 2) was built with well insulated walls and cover to accommodate one ingot. It has one coke-oven gas-burner, capacity 1500 ft³/h, to restore when necessary the heat lost by the pit when idle. So as to prevent unwanted air being draw ninto the pit and cooling it, the air for combustion is supplied under forced-draught conditions.

The instrumentation provided for the trials was limited to **U**-gauges indicating the air and gas flow and a thermocouple embedded in the pit wall as shown in Fig. 2.

Method of Operation

The pit operatives are supplied with a schedule of index times which shows:

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The authors are with the Appleby-Frodingham Steel Company.

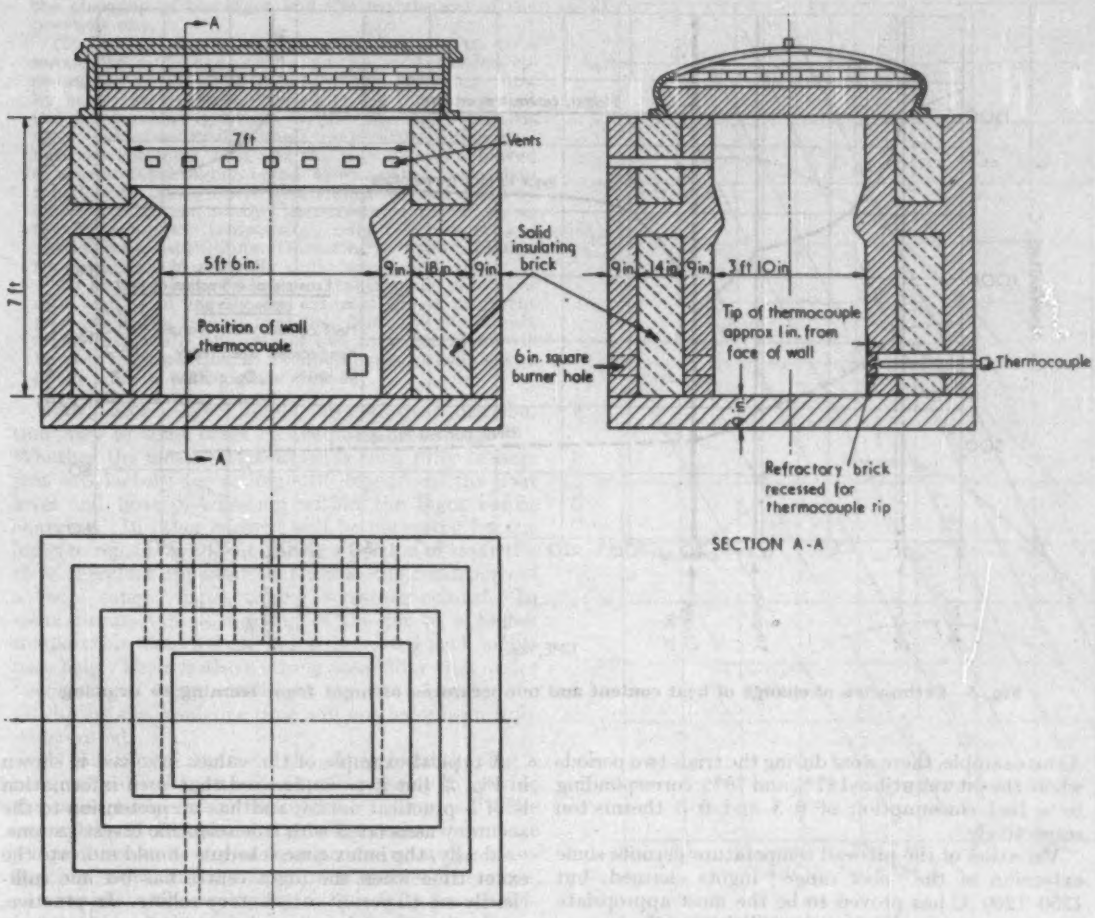


Fig. 2—Diagrammatic arrangement of pit

(*a*) The range of ingots which from their track times (tap to strip), and transfer times (strip to charge), have a satisfactory heat content for charging to the pit

(*b*) The time the ingot should remain in the pit before rolling, as a function of track and transfer time.

Normally the pit was charged with the 4th or 5th ingot from the cast.

Results of Trials

The trials commenced on 4th December, 1956, after the pit had been brought to heat-equilibrium conditions with the internal temperature of 1250° C. Up to 15th June, 1957, 500 ingots have been conditioned in the pit and rolled. The number of occasions when an ingot has been sent back from the mill as too hot or too cold, in the opinion of the roller, have been exceedingly few (13 instances), and these were confined to the initial experimental period. It has been the general experience that when mill breakdowns have caused a delay in drawing the pit, a latitude of 1½ h excess time in the pit, and even 4 h in the case of ingots charged belonging to the very 'hot range', has not proved detrimental.

The quality of the ingots (as regards percentage defectives, etc.) has proved to be at least as good as, if not better than, that from the gas-fired soakers, and generally 1% gain in yield has resulted. There has been little scale loss as compared with conventional soakers.

Maintenance of the pit has been virtually nil, and the structure is still in excellent condition.

Fuel consumption whilst the pit is idle has averaged 1000 ft³/h of coke-oven gas, which is consistent with a calculated radiation loss of approximately 1 therm/h and an overall heat utilization of approximately 20%. In the conditions under which the pit has been utilized during the trial, 30 ingots have on the average been charged per week with a mean residence time of 2½ h each. This relatively poor usage has left the pit idle for a mean period of 93 h/week, and the gas which had to be used to keep it hot corresponds to 1·67 therms/ton of ingot charged. It is evident that better pit utilization would lead to a lower heat requirement per ton.

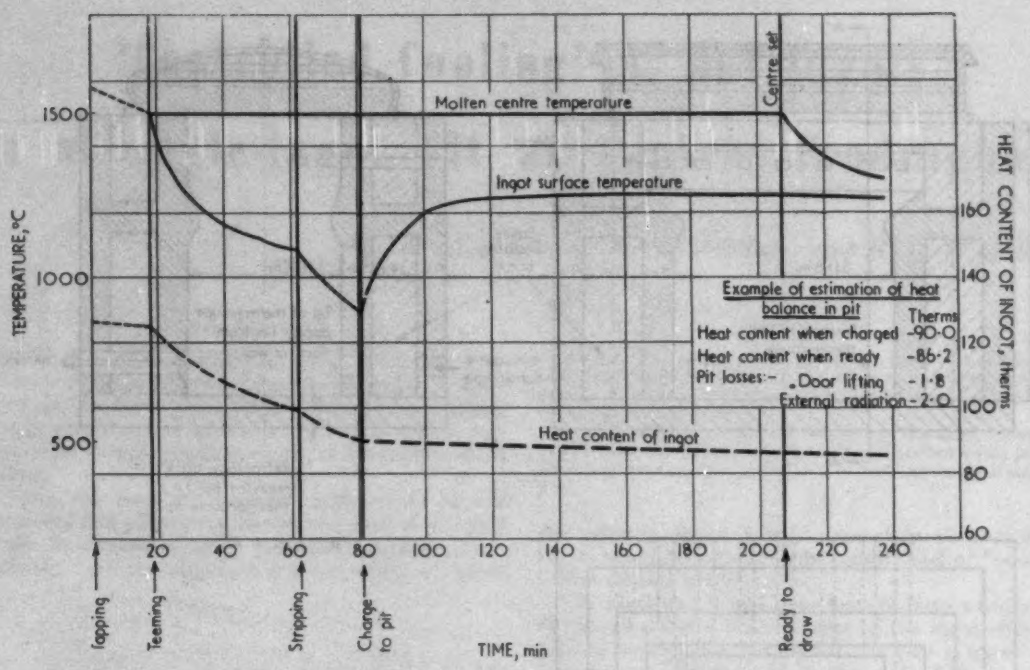


Fig. 3—Estimation of change of heat content and temperatures of ingot from teeming to drawing

As an example, there were during the trials two periods where the pit was utilized 87% and 78%, corresponding to a fuel consumption of 0·3 and 0·5 therms/ton respectively.

Variation of the pit-wall temperature permits some extension of the 'cool range' ingots charged, but 1250–1260° C has proved to be the most appropriate temperature to suit general conditions.

The wall-thermocouple temperature readings give the operator the necessary information regarding the condition of the pit before charging and gas requirements when the pit is empty.

PRELIMINARY INVESTIGATIONS

Index Time Schedule

As the tapping temperature is controlled within reasonable limits, it has been assumed constant in the building of the basic index time schedule.

The latter has necessitated the assessment of:

(i) The loss of heat of the metal between tapping and teeming

(ii) The heat content of the ingot in the mould prior to stripping.
Some data on the subject were available from B.I.S.R.A. and those for 8-ton ingots has been used as a basis.

(iii) The heat content of the ingot prior to charging.
Experimental data on the rate of cooling of a stripped ingot are scanty, and offer scope for future investigation. A small amount of data were however available from experiments carried out at Appleby-Frodingham in the early thirties, and advantage has been taken of this to confirm the views held on the subject or otherwise.

(iv) The heat exchange between the ingot and pit walls whilst the ingot is in the pit, and the influence of it on the total time required to solidify the centre.

A typical example of the values involved is shown in Fig. 3, but it is emphasized that such information is of a practical nature and has no pretension to the accuracy associated with true scientific investigations.

Ideally, the index time schedule should indicate the exact time when the ingot centre has become sufficiently set to permit satisfactory rolling. In practice, a tolerance must be allowed to cater for variation in conditions of the ingot, even when the teeming and stripping times of the particular ingot are known accurately and the pit is at the appropriate temperature. The calculated index times shown in Fig. 4 include this tolerance.

For normal routine application, a still wider tolerance has to be allowed as the exact ladle temperature and the correct teeming and stripping times for the individual ingot are not known, and other variables such as off-standard condition of the pit walls have to be catered for. The extra tolerance which can be allowed will depend on the heat content of the ingot charged into the pit; it can be wider for ingots in the 'hot range' (short track and transfer times) than for ingots in the 'cool range' on the basis of the following argument.

The cooling of the ingot in the pit can be considered as taking place in three stages:

(1) Relatively rapid transfer of heat (mainly latent heat of solidification) from the ingot centre to the ingot surface, the temperature of which had come down while in the mould and after stripping. During this stage almost no heat transfer takes place from the ingot to the pit lining; on the contrary the ingot receives heat from the wall at a rate which will depend on the extent the wall surface had been cooled during

the charging of the ingot and the withdrawal of the previous one.

(2) Cooling at a gradually increasing rate up to a maximum and then, owing to the molten zone receding to nothing, at a gradually decreasing rate, by heat transfer to the pit wall. During this period the temperature gradient within the ingot flattens more and more until a small temperature differential between the ingot face and the wall face is achieved at a mean level higher, equal, or somewhat lower than the desired one. There is no need at this stage to make regular use of the thermocouple provided, as the ingot surface temperature only becomes critical outside reasonable limits. Operating to a proved index time schedule is generally quite adequate.

(3) Further loss of heat now takes place at a slow rate controlled mainly by external losses from the pit. Since the rate of heat loss from the pit is only about 1 therm/h, the rate of loss from the ingot will be even less than this, as a reduction of the heat stored in the walls is taking place as well.

With 'cool range' ingots internal heat distribution may in some cases be adequate after stage (1). Whether the mean temperature is then fully or only just satisfactory for rolling will depend on the heat level and heat distribution within the ingot before charging. In other cases it will be necessary for the ingot to remain in the pit during a portion of stage (2). It is therefore apparent that under the conditions of a 'cool range' ingot, timing is rather critical. In some circumstances, heating of the pit to a higher temperature than normal before receiving such ingots may help. There is also a strong possibility that under 'cool range' ingot conditions the heat lost by the pit during the residence time will not have been fully recuperated.

A 'hot range' ingot on the other hand, having a heat content well in excess of that necessary to provide the mean temperature required for rolling, will have imparted sufficient heat to the wall to cause its surface temperature to be higher than necessary at the drawing time shown in the index time schedule. Therefore, an extended stay during stage (3) is fully permissible and perhaps desirable under some conditions.

The normal routine index time schedule (*see* Table I)

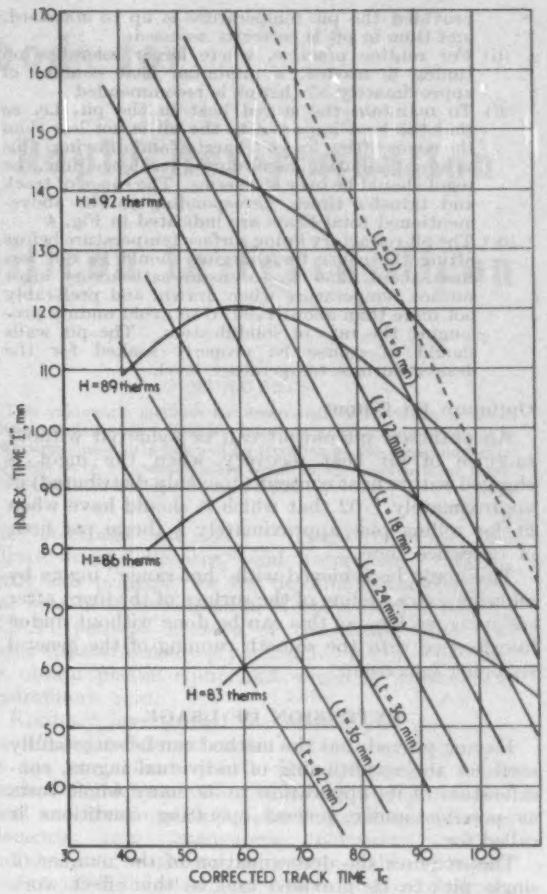
Table I

SINGLE INGOT PIT PRACTICAL INDEX TIME SCHEDULE

(Time in pit, min)

For 1250° to 1260° C pitwall surface temperature

Strip to Charge Time t, min	Tap to Strip Time T_C, min									
	50	55	60	65	70	75	80	85	90	95
50	65	...								
45	75	70	...							
40	85	75	70	...						
35	100	90	85	75	...					
30	120	110	95	85	75	...				
25	145	130	115	105	85	75	...			
20	165	150	140	125	110	95	80	...		
15	190	170	160	145	130	115	100	80	...	
10	205	195	185	170	150	135	120	110	95	...
5	225	215	205	190	175	160	145	130	115	95



Key

I = Index time = Minimum time in pit
T_c = Corrected track time = Actual time in mould + 18 min
t = Transfer time = Actual time ingot is stripped before charging to pit
H = Assessed total heat content of ingot at moment of charging to pit

Fig. 4—Single-ingot pit: index times and total heat when charged to pit

finally adopted by the soaker management with pit temperature 1250–1260° C follows closely the calculated index times for the lower range of total heat, with progressively longer residence times for the hotter ingots. (The order of deviation is approximately 10 min for ingots in the 89-therm range to approximately 30 min in the 92-therm range.) This deviation may be due to the calculated times being somewhat low for the hotter ingots, but the practice is also consistent with the argument developed above, that a longer residence time, not necessarily required, may safely be allowed.

Normal Conditions of Operation

From the test data and estimated heat balance it is concluded that:

(i) Ingots having a total heat content when charged as low as 83 therms can be rolled satisfactorily,

provided the pit temperature is up to standard, and time in pit is correctly assessed

(ii) For routine practice, where larger tolerance on timing is needed, a minimum heat content of approximately 85 therms is recommended

(iii) To maintain the stored heat in the pit, i.e. so that the heat imparted to the pit is not less than the cover-lifting losses (charging and drawing) plus external radiation losses during residence time, the ingot should be over 89 therms. The range of track and transfer times corresponding to the above-mentioned total heats are indicated in Fig. 4

(iv) The pit refractory lining surface temperature before lifting the cover for charging should be not less than about 1250° C, to ensure satisfactory ingot surface temperature when drawn, and preferably not more than about 1280° C to avoid unduly prolonging the rate of solidification. The pit walls should of course be properly soaked for the desired surface temperature level.

Optimum Pit Output

An optimum pit output can be achieved without sacrifice of pit heat recovery when the ingot is charged with a heat content (unevenly distributed) of approximately 1·02 that which it should have when fit for rolling plus approximately 1 therm per hour of residence time.

This could be achieved with ' hot range ' ingots by allowing extra cooling of the surface of the ingot after stripping, so long as this can be done without undue interference with the smooth running of the general stripping operation.

EXTENSION OF USAGE

Having proved that the method can be successfully used for the conditioning of individual ingots, consideration of its application to as many whole casts as possible under general operating conditions is called for.

This requires the determination of the number of single pits to be provided and to this effect work studies will have to be made to ascertain:

(i) The degree of irregularity of melting furnace tappings which has to be allowed for

(ii) The recurrence and extent of unavoidable delays to traffic and stripping

(iii) The normal sequence in the rate of rolling and the possible deviation.

For the sake of economy, the single pits will have to be grouped and the use of multi-cell units has to be considered.

APPLICATION TO MULTI-CELL PIT

Pit Construction and Equipment

(*a*) The refractory lining should have a high heat capacity and the thermal insulation should be as effective as possible:

(i) To permit the use of the heat stored in the lining, to restore the wall skin temperature at the desired level after the flash cooling which results from lifting the cover to draw and charge the ingot, and to permit such initial supply and subsequent absorption of heat to proceed without appreciable change in the average temperature of the refractory wall

(ii) To ensure that the reasonably flat internal temperature gradient required at the end of the residence period is obtainable from top to bottom of the ingot

(iii) To keep the pit heat losses low.

(*b*) The pit should be effectively sealed against air infiltration, and burners for idle-period firing should have a forced-draught air supply.

(*c*) Instrumentation should include a multi-switch temperature indicator serving one thermocouple embedded in the refractory lining at each cell, and a flow recorder for the total coke-oven gas to the pit with indicators showing gas and air flow to individual cells.

(*d*) To prevent the ingress of unwanted air into the pit the burner waste gases should be collected into a downtake built within the cell wall and removed through a suitable duct at the bottom of the pit.

(*e*) Recuperation of the resulting waste heat for the purpose of reducing the amount of live gas needed during idle periods should be arranged for if found economical.

Charging Procedure

It is estimated that, provided the ingots from an 80-ton cast are charged and drawn for rolling in the same order as teeming and stripping has proceeded, each ingot could be drawn during normal rolling without deviating by more than 15 min from the index time appropriate to it. As an example, should the first ingot be drawn at the correct index time, the index time of the eighth ingot, the last of a cast, would only be overrun by approximately 15 min.

Nominally, a separate index time schedule will be required for the middle and the end cells, to take into consideration the difference in heat dissipation area.

On the other hand, some compensation could be obtained by varying the amount of initial cooling of each cell either prior to introducing the ingot or in the early stage of residence.

CONCLUSIONS

The method of conditioning ingots between casting and rolling tried at the Appleby-Frodingham plate mill has proved very satisfactory, from the point of view of both fuel economy and ingot surface conditions.

On the other hand, it is appreciated that the general application of the method will only succeed fully when the deviation from expected casting and stripping times and from the intended sequence of rolling are reasonably controlled. The progress made at Appleby-Frodingham in latter years towards this achievement indicates that there are good prospects of smoothing over most of the difficulties.

Under these conditions the fuel consumption per ton of ingot may tend to go down towards 0·3 therms/ton as against the approximate 3 therms/ton consumed in the latest gas soakers installed, when dealing under similar conditions with ingots of equivalent track times.

It is also expected that the better yield shown will stand with an improvement from the present 90–91%.

The method of controlled cooling should be applicable to all ingots of ordinary steel quality which can be charged with an adequate heat content.

Acknowledgment

The authors wish to express their appreciation of Mr. P. Charlesworth's co-operation in conducting the trials.

Methods for the Rapid Determination of Silicon in Ferrosilicon

By Sigurd Velken

SYNOPSIS

Two volumetric methods for determination of silicon in ferrosilicon are described. Both are based on precipitation of silicon as potassium fluosilicate followed by titration of this compound. The methods have a reproducibility equal to the conventional gravimetric methods and are far more rapid. 1451

Introduction

IN THE CONVENTIONAL METHODS for the determination of silicon in ferrosilicon the alloy is decomposed by an oxidizing basic flux. The melt is dissolved in an excess of hydrochloric, sulphuric, or perchloric acid, and the silica dehydrated by evaporation. The precipitate is collected on a filter paper, washed out, and ignited, and the silica calculated as the loss in weight by treatment with hydrofluoric acid.

The filtrate and washings always contain small amounts of colloidal silica, and in accurate work the greater part of this is rendered insoluble by a second evaporation of the solution. The silica left behind in the second filtrate will amount to about 1 mg depending on the type of acid used for the dehydration and the conditions prevailing. The more important of other sources of error (with the exception of ignition temperature) will also cause low results.

The methods based on dehydration are slow. In work where the greatest accuracy is required, the time necessary will be at least 24 h. A more rapid and at the same time equally reliable method for determination of silicon in ferrosilicon, intended for control purposes, was the object of this investigation.

POTASSIUM FLUOSILICATE METHOD

Principle

The method is based on the reaction between silicic acid and potassium fluoride, in acid solution giving a compound with the formula K_2SiF_6 of low solubility. The potassium fluosilicate may be titrated with sodium hydroxide according to the following equation:

$$K_2SiF_6 + 4\ NaOH \rightarrow SiO_2 + 2\ H_2O + 4\ NaF + 2\ KF$$

Earlier Work

The above principle was known about 50 years ago and proposed for the volumetric determination of K_2SiF_6.[1] Later it has found some application in Eastern Europe and Japan for the determination of silica in silicates and silicate rocks,[2] fluorspar and cryolite,[3] steel and cast iron,[4, 5, 6] steel, iron, slags, and silicate rocks,[7] silicates,[8] and water-glass.[9] Apparently this principle for the determination of silicon has been little considered in Western Europe and the U.S.A., perhaps because of the inconvenience of using apparatus made of platinum. It is now possible to obtain plastic equipment which is resistant to hydrofluoric acid.

Kordon[10] investigated the solubility of potassium fluosilicate in different media and determined the pH at the equivalence point. He developed a rapid method for determination of silicon in pig iron and steel and investigated the effect of different alloying elements. Iron, manganese, chromium, nickel, molybdenum, vanadium, tungsten, cobalt, and copper do not affect the volumetric determination of silicon. Aluminium, titanium, zirconium, and tantalum are, like silicon, liable to form complex fluorides of low solubility. They are filtered off together with the potassium fluosilicate and cause an increased consumption of sodium hydroxide when present in sufficient amounts.

Development of Methods

Since ordinary grades of ferrosilicon are insoluble in acids other than hydrofluoric acid, the decomposition of the ferrosilicon using a basic oxidizing flux, followed by precipitation of the silicon as potassium fluosilicate, was first considered. Trials were made to ascertain the best conditions for decomposition by sodium peroxide with a view to using a procedure based on the paper of Gotô and Kakita.[7]

The accuracy of the procedure was investigated on samples of known silicon content.

METHOD 1. Decomposition by Fusion with a Mixture of Potassium Carbonate and Sodium Peroxide

Special Apparatus—Beakers, funnels, and stirring rods of a plastic which is resistant to hydrofluoric acid.

Reagents Required

Fusion mixture: Mix powdered potassium carbonate and sodium peroxide in the proportion of 1:1 by weight

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The investigation was carried out at SINTEF (The Engineering Research Foundation at the Technical University of Norway), Trondheim, for the Norwegian Ferrosilicon Producers' Association.

Mr. S. Velken, formerly with SINTEF, now with Elektrokemisk A/S, Fiskaa Verk, Kristiansand S., Norway.

Nitric acid (sp.gr. 1·4)
Hydrofluoric acid (40%)
Potassium chloride
Potassium chloride (20% solution): Dissolve 200 g KCl in water and dilute to 1000 ml
Sodium hydroxide (0·25N): Standardize the solution against either potassium biphthalate or succinic acid, using phenolphthalein as an indicator.

As the reagents, especially the hydrofluoric acid, are usually contaminated with some silicon, a blank should be run on every new batch.

Using the theoretical normality for calculation of the silicon content, the sodium hydroxide must be prepared free from carbonate and stored protected from the atmosphere by a soda–lime tube. A simple and reliable method is to standardize the sodium hydroxide against a sample with known silicon content, carrying out the standardization as in the following procedure. The titration is now automatically corrected for the silicon present in the reagents, no extra blank being necessary. In this case it is of no consequence if the sodium hydroxide contains some carbonate. For routine work standardization of the sodium hydroxide against a standard sample is therefore recommended.

Procedure

Thoroughly mix 0·2 g of finely ground ferrosilicon, grade 75% silicon, with 2·5 g fusion mixture in a nickel crucible. Use a platinum wire for the mixing. Add a surface layer of 2·5 g fusion mixture and cover the crucible with a nickel lid. (For ferrosilicon of other grades adjust the sample weight to give the same amount of silicon).

Fuse as described.[11] While the crucible and lid are still warm, place both in a 250-ml plastic beaker and extract with water. Rinse the crucible and lid with hot water and a little nitric acid. Add 35 ml nitric acid and if necessary dilute with water to about 80 ml.

Add 6 g potassium chloride, dissolve, and allow to cool. If the volume is more than 80 ml, proportionate amounts of potassium chloride and nitric acid should be used.*

Stir in 10 ml hydrofluoric acid and a little paper pulp. Cool the solution to as low a temperature as possible, preferably in ice water, for 10–15 min, stirring occasionally. To accelerate the quantitative precipitation of the potassium fluosilicate it may be advantageous to use a stirring motor with a plastic stirrer. Three minutes at 500–1000 rev/min will be sufficient and the solution may be filtered immediately if it is sufficiently cool.

Filter on a paper-pulp pad in a plastic funnel. Transfer the entire residue to the pad and wash the beaker and pad with cold potassium chloride (20%). Use as little washing solution as possible, preferably less than 100 ml. Precipitate and pad are sufficiently washed when 10 ml of the washing solution become alkaline to methyl red on the addition of one drop of 0·25N sodium hydroxide. Remove the liquid in the stem of the funnel by slight suction and transfer pad and precipitate to a 300-ml Erlenmeyer flask. Remove the last traces of precipitate from the funnel with a piece of filter paper moistened with water, place the funnel in the neck of the Erlenmeyer flask, and rinse down with 50 ml of hot water (previously boiled). Shake the flask to disintegrate the pad and titrate with 0·25N sodium hydroxide in hot, nearly boiling solution to a pink colour. As an indicator use ten drops of phenolphthalein (1%). Heat the mixture to boiling for a short period during which the colour should be retained. Alternatively, continue the titration until the pink colour persists on heating.

1 ml 0·25N NaOH = 0·0017538g Si.

Time required: One hour.

Results

Determination of Si in ferrosilicon, grade 75%Si

Sample	*D**	*A†*	*Standard deviation*	*Gravimetric*
N.B.S. sample no. 58	10	75·56%Si	0·21%Si	75·60%Si‡
Commercial	4	74·47% Si	0·10%Si	74·48%Si‡

* Determinations † Average ‡ Certificate value

The sodium hydroxide was standardized against succinic acid. When standardizing the hydroxide against the National Bureau of Standards sample no. 58, the result for the commercial sample was 74·48%Si, i.e. practically the same.

Effect of Aluminium

In ordinary ferrosilicon, aluminium is the only element which may possibly be present in amounts sufficient to affect the result. To find how much could be tolerated, known amounts of aluminium nitrate were added to the N.B.S. sample no. 58 before precipitation of the potassium fluosilicate.

Aluminium up to 3% is without any effect on the percentage of silicon found. With more than 3% aluminium, the sharpness of the endpoint is affected, and the pink colour fades on boiling. It is recommended that the titration mixture should be boiled a few times more and a little longer than usual to see if the colour of the indicator persists.

Above 4% aluminium the values for silicon tend to be low. This result is not in agreement with the investigation of Kordon,[10] who found high values for silicon when aluminium was present. On the other hand Tananaeff and Babko[2] determined silicon in kaolin and clay apparently without any influence of aluminium.

Trials have shown that when ferrosilicon is decomposed by potassium hydroxide and potassium nitrate, or by the wet decomposition described in method *2*, much higher amounts of aluminium may be tolerated without affecting the result. This seems to indicate that presence of sodium salts lower the solubility of the aluminium–fluorine compound.

The effect of high amounts of aluminium, however, is not investigated further in this report. The content of aluminium in ordinary grades of ferrosilicon rarely exceeds 3%, and up to this percentage method *1* may be used without any extra precaution.

* Some analysts prefer to decompose ferrosilicon with sodium hydroxide and potassium nitrate. In this case use potassium hydroxide instead of sodium hydroxide. The amounts of hydroxide, acid, and potassium chloride should be adjusted before the precipitation with hydrofluoric acid to give the same concentrations as above.

For contents exceeding 3%, fuse with potassium hydroxide and potassium nitrate or dissolve in nitric–hydrofluoric acid as described in method *2*, which is intended for rapid control where this is necessary.

METHOD 2. Wet Method of Decomposition with Nitric–Hydrofluoric Acid

The conventional decomposition of ferrosilicon with sodium peroxide or alkali hydroxide and nitrate described in method *1* is rather lengthy and great care must be exercised. To obtain a good result, an experienced analyst is required.

It is possible to decompose ferrosilicon with nitric–hydrofluoric acid without any loss of silicon. Volatile SiF_4 will react momentarily with excess hydrofluoric acid to give H_2SiF_6, and the total reaction will be:

$$Si + 4\ HNO_3 + 6\ HF \rightarrow H_2SiF_6 + 4\ NO_2 + 4\ H_2O$$

The volatility of H_2SiF_6 is small at temperatures below 80° C. The rise in temperature may be regulated by the amount of nitric acid present. At the same time the violence of the reaction is diminished, thus reducing the loss of SiF_4 to negligible amounts.

Special apparatus and reagents—See method *1*.

Procedure

Into a plastic beaker weigh 0·2 g ferrosilicon, grade 75% silicon, and cautiously add 30 ml nitric acid (sp.gr. 1·4). Then pour 10 ml hydrofluoric acid (40%) down the side of the beaker. If both additions are carefully done, the reaction will proceed slowly without any danger of vigorous effervescence. To start the reaction it may be necessary to agitate the beaker a little.

When the reaction has subsided, agitate the beaker for a few seconds to expel most of the nitrous gases and to dissolve any remaining particles. Rinse the sides of the beaker with 20 ml of water and add with stirring 30 ml potassium chloride (20%) and a little paper pulp, and cool. Then proceed as described under method *1*.

Notes

When using extremely finely ground material (< 300 mesh) a little loss during the dissolution may occur by too vigorous a reaction. The violence of the reaction may be reduced by adding the necessary 6 g potassium chloride before the hydrofluoric acid. Potassium fluosilicate is now precipitated on the surface of the material and the reaction will proceed so slowly that it is necessary to heat the beaker in a water bath for about 15 min to dissolve all the particles. Experiments have shown that under these conditions the heating may be done without any danger of losing silicon.

Ferrosilicon may contain small amounts of silicon carbide which remains as a dark green residue after the dissolution in nitric–hydrofluoric acid. If total silicon is wanted, method *1* should be used.

Time required: 45 min.

Results

Determination of Si in N.B.S. sample no. 58.

Determinations	*Average*	*Standard deviation*	*Certificate value*
12	75·89%Si	0·13%Si	75·60%Si

The sodium hydroxide was standardized against the same sample following method *1*.

Determination of Si in a commercial sample, grade 75%

Analyst	*Determinations*	*Average*	*Standard deviation*
A	10	77·64%Si	0·14%Si
B	9	77·77%Si	0·21%Si

The sodium hydroxide was standardized against a standard sample following the same procedure. Determinations were distributed over four days.

To afford a basis of comparison the same sample was analysed by 16 different laboratories following the gravimetric procedure.

Average of gravimetric determinations:	77·46%Si
Standard deviation:	0·36%Si

DISCUSSION OF RESULTS

The values obtained for silicon in ferrosilicon by both modifications of the potassium-fluosilicate method are in good agreement with the values from gravimetric determinations. Reproducibility is of the same order for both modifications. It is equal to, and probably better than, the reproducibility obtained by conventional gravimetric methods.

In this connection it may be mentioned that members of the Norwegian Ferrosilicon Producers' Association over a period of about a year have used both modifications in addition to the gravimetric method for determinations of silicon in 20, 45, 75, and 90% ferrosilicon. The data regarding the reproducibility seem to confirm the findings in this report.

Determinations of Silicon in other Ferro-alloys

The potassium fluosilicate methods may be used for determinations of silicon in some other ferro-alloys, e.g. silico-manganese and silico-chromium.

Acknowledgments

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A Potentiostat Technique for Studying the Acid Resistance of Alloy Steels

By C. Edeleanu, M.A., Ph.D.

SYNOPSIS

In the present paper a number of properties, all of which are included in the general term 'acid resistance,' are defined, measured, and compared by means of a potentiostat technique. The method is considered satisfactory for a preliminary study of a group of alloys.

Changes in chromium steel composition can lead to either improvement or deterioration of properties depending on the circumstances under which the steel is exposed to the acid. It is now possible to predict under which conditions an alloy is likely to show its best or worst properties. 1430

Introduction

RESISTANCE TO ACID SOLUTIONS is, in many cases, a complex property which cannot be measured on any absolute scale. Using conventional methods it is sometimes difficult to follow, with any degree of certainty, the effects of any given change in composition or of heat-treatment. As is widely known, a change in composition which may lead to a great improvement to one particular concentration of a given acid may, at the same time, also lead to a decrease in resistance to a different concentration of that acid or to other acids.

The purpose of the paper is to show how, by using the potentiostat techniques previously described,[1, 2, 3] it is possible to learn a great deal about the corrosion characteristics of alloys, and how it is possible to understand some of the apparent discrepancies mentioned above.

The technique used has much in common with those suggested by other workers.[4–7] It may not be suitable for all studies but it does seem to provide an adequate compromise between a desire to obtain results of great accuracy and the necessity to carry out an adequately large number of tests in a field in which there are a great many variables to investigate. The theoretical considerations which lead to the present treatment have been outlined before[1] and will be considered in greater detail elsewhere. These are not now discussed since their acceptance is not necessary for the present purpose.

CORROSION CHARACTERISTICS OF STEELS

From a corrosion point of view, with certain reservations, there are no 'bad' and 'good' steels and the various alloys are only different. The addition of 13–20% Cr, for instance, which makes steel 'stainless' also leads to a much more rapid attack by certain concentrations of sulphuric acid, while the addition of 1–3% Mo to an 18–8 steel may, in certain cases, cause an increase in corrosion in nitric acid but lead to improved resistance to sulphuric acid.

As will be shown below it is possible to determine a 'potential/current' (P/C) diagram for each steel and from these it is possible to predict under what conditions the steel will have an adequate resistance.

For convenience the properties of steels can be divided under the following headings:

(i) Resistance to highly oxidizing conditions
(ii) Range of passivity
(iii) Rate of corrosion of the passive metal
(iv) Stability of passivity
(v) Maximum rate of corrosion
(vi) Relative nobility.

The meaning of these will be made clear in the next section.

POTENTIAL/CORROSION-RATE CURVE

As explained elsewhere[1] the rate of corrosion in a simple case is dependent on potential in the manner shown in Fig. 1 which gives diagrammatically the curves for two different steels. This type of curve will be called a potential/corrosion-rate curve and is obtained by carrying out loss of weight measurements at constant potential using the potentiostat.[1] The potential/corrosion-rate curve can be regarded as an anodic polarization curve by substituting the equivalent current for the corrosion rate and from it, it is

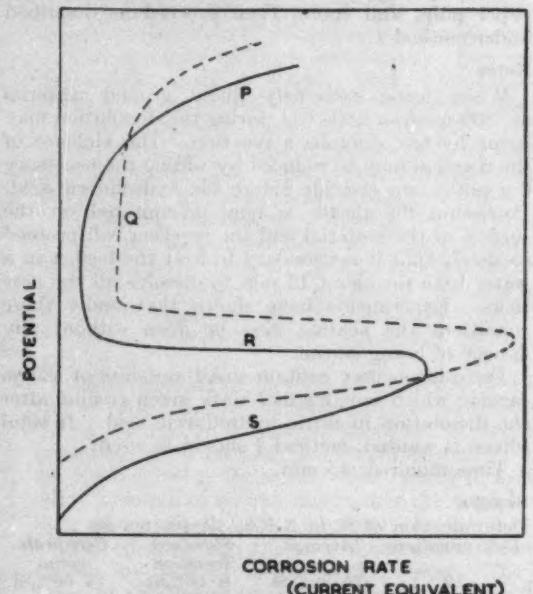

Fig. 1—Diagrammatic potential/corrosion-rate curves for two hypothetical steels

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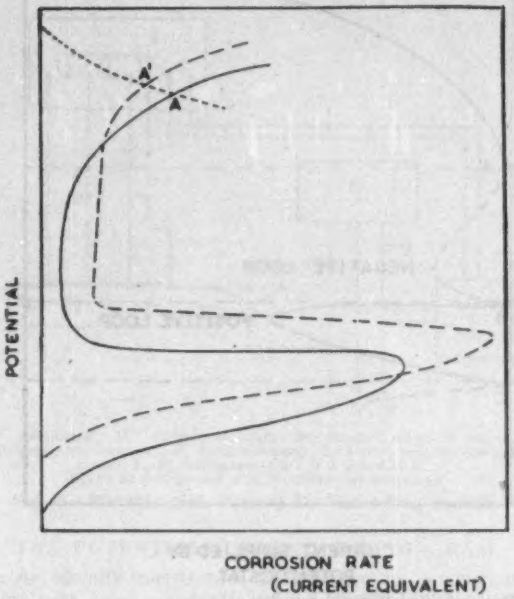
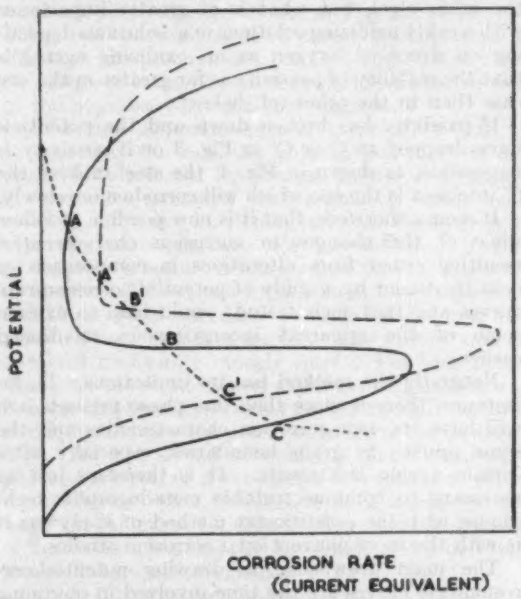


Dotted line represents rate of cathodic reaction (current equivalent × − 0·1)

Fig. 2—Diagrammatic representation of corrosion under highly oxidizing conditions

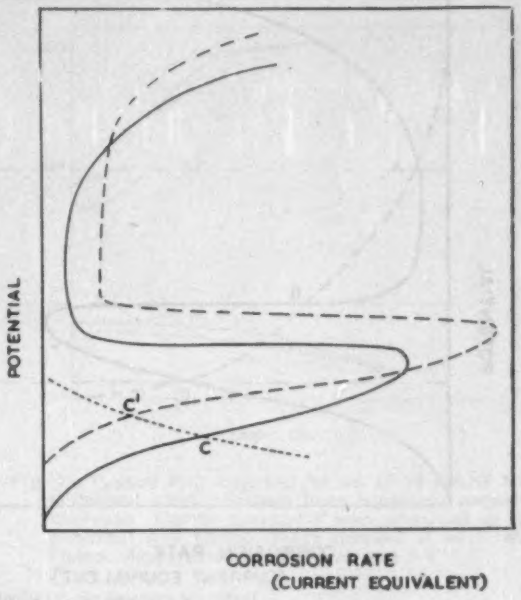
possible to determine the rate at which the anodic (electron-producing) reaction tends to occur at any given potential.

If the specimen corrodes naturally (i.e. it is not polarized), a cathodic (electron-consuming) reaction must also occur at exactly the same rate as the anodic reaction, and if the two polarization curves are drawn on the same diagram any point of intersection represents a possible corrosion potential for that particular system and also gives the rate of corrosion.[8]



Dotted line represents rate of cathodic reaction (current equivalent × − 0·1)

Fig. 3—Diagrammatic representation of corrosion in a weakly oxidizing medium



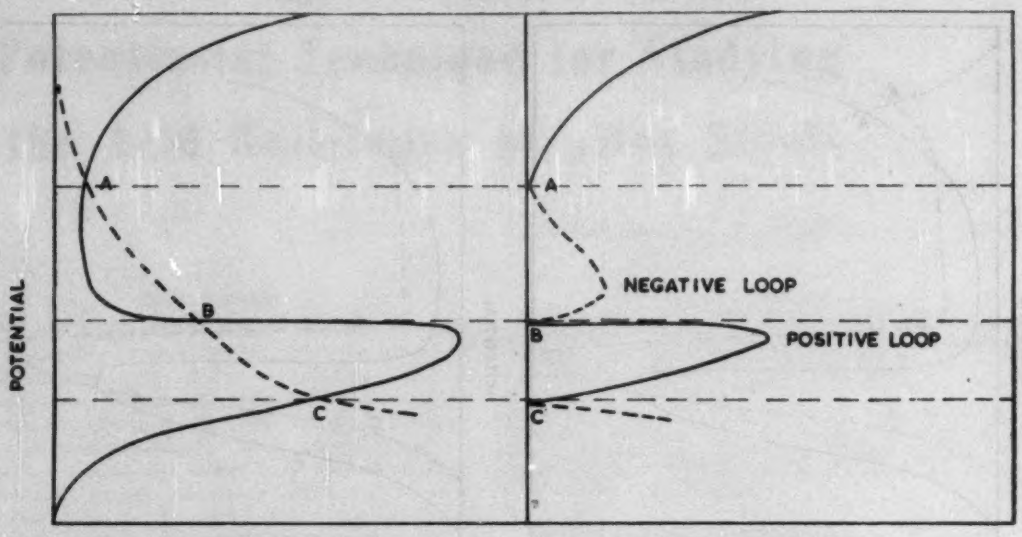
Dotted line represents rate of cathodic reaction (current equivalent × − 0·1)

Fig. 4—Diagrammatic representation of corrosion in a non-oxidizing medium

If a highly oxidizing solution is considered, the cathodic polarization curve occurs at a high potential, as shown in Fig. 2. From this it can be seen that the *resistance to highly oxidizing conditions* is controlled by the position of portion P of the potential/corrosion-rate curve, and the rates of corrosion of the two steels are represented by the points A and A'.

The *range of passivity* is given by the length of portion Q and represents the range of potential over which the steel has a very low rate of corrosion. In acid solutions the *rate of corrosion of passive metal* is never zero and in the stronger acids, particularly at elevated temperatures, appreciable rates of corrosion are found and are indicated by the lateral position of portion Q.

As is well known, passivity can be a somewhat unreliable state and it may or may not be stable in a solution in which an intersect occurs within portion Q. The reason for this is shown in Fig. 3, in which it is seen that in such a case there are three intersects between the anodic and cathodic curves. Intersects A and A' are, as before, possible and represent the passive potentials and rates of corrosion, but when a specimen is first placed in a solution a certain period of time is necessary for the various reactions to settle down to the steady state. During this period the position of A moves up and down and, if by any chance it falls sufficiently for points A and B to coincide, a point of 'no return' is reached. This is so because at B, although the anodic and cathodic reactions



Dotted line represents rate of cathodic reaction (current equivalent × − 0·1)

Fig. 5—Relation between potential/corrosion-rate diagram and potential/current (P/C) diagram

occur at the same rate and there is neither an excess nor a deficiency of electrons with time, the anodic reaction is favoured by a drop in potential more than the cathodic reaction; therefore any further small accidental fall in potential will lead to the production of excess electrons and thus to a rapid fall in potential to point C or C', which represent the active potentials and rates of corrosion. In fact, if a potential/time curve is drawn in a case in which point B is reached, there is a very sudden drop in potential just as expected.[9] This matter is discussed again later but the *stability of passivity* is a measure of the probability of the potential A being stable.

The *maximum rate of corrosion* is taken to be the maximum of the ' loop ' formed by portions R and S; it is the highest rate of corrosion of the steel and the rate at which it corrodes just before anodic passivity establishes itself.[2]

The *relative nobility* of the steel depends on the position of portion S and, as shown in Figs. 5 and 8, it controls the rate of corrosion of the non-passive metal as represented by points C and C'. The more noble an alloy is the less rapidly it will corrode in solutions in which passivity is impossible.

The two hypothetical steels shown in Figs. 2, 3, and 4 differ from each other in all the above respects. Under really highly oxidizing conditions, as shown in Fig. 2, high corrosion rates are inevitable with both steels so that neither can be considered for use at elevated temperatures, but the steel represented by the broken line and making the intersect A' has the lower corrosion rate. At a somewhat lower potential both steels have very low corrosion rates, but there has been a reversal and the corrosion rate of the steel making the A' intersect is now higher (Fig. 3). Over the range of passivity the corrosion rate of both steels may, however, be so small that, using crude measuring techniques, the steels may be regarded as identical; the difference becomes obvious when the temperatures are sufficiently high to make the rates of corrosion of practical significance.

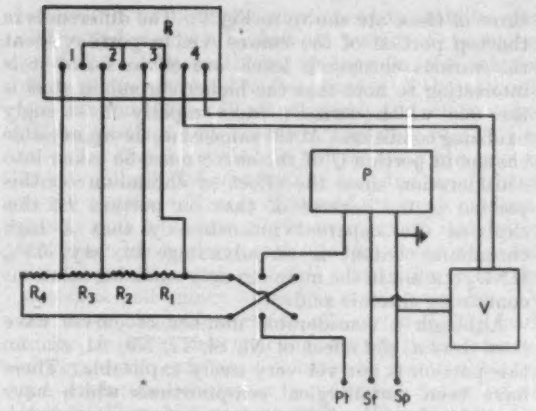
The range of passivity extends to lower potentials for the steel making the intersects A and B (Fig. 3) so that this steel can be successfully used in solutions having lower redox potentials than is the case with the other steel, but what is of greater importance with weakly oxidizing solutions (e.g. solutions depending on dissolved oxygen as an oxidizing agent) is that the stability of passivity is far greater in the one case than in the other (cf. below).

If passivity has broken down and the potentials have dropped to C or C' in Fig. 3 or if passivity is impossible, as shown in Fig. 4, the steel making the C' intersect is the one which will corrode more slowly.

It seems, therefore, that it is now possible to follow some of the changes in corrosion characteristics resulting either from alterations in composition or heat-treatment by a study of potential/corrosion-rate curves and that such a study could help to explain some of the apparent inconsistencies mentioned earlier.

Naturally the method has its limitations. If, for instance, there is more than one phase present each will have its own corrosion characteristics and the same applies to grain boundaries, especially after certain ageing treatments. It is therefore just as necessary to combine suitable metallographic techniques with the potentiostat method of study[3] as it is with the more conventional corrosion studies.[10]

The main drawbacks to drawing potential/corrosion-rate curves are the time involved in obtaining these with any degree of accuracy by gravimetric methods and the lack of sensitivity of the method where really low corrosion rates are involved.



P, potentiostat; Pt, platinum electrode; St, standard saturated calomel electrode; Sp, specimen; V, valve voltmeter; R, 4-point recorder (10 mV range); R_1–R_4, resistances of 0·1, 0·9, 9, and 90 Ω
R_4 can be used instead of R_1 if currents are very small

Fig. 6—Electric circuit used for recording results

THE POTENTIAL/CURRENT (P/C) DIAGRAM

As already mentioned, a specimen in a solution can only take a potential at which the anodic and cathodic reactions occur at the same rate and these are, for instance, the potentials *A*, *B*, and *C* of Fig. 3. At any other potential, currents must flow either to or from the specimen and the magnitude and sign of these currents are a measure of the difference in the rates of the two types of reaction. If, therefore, the current supplied by the potentiostat to maintain the potential of the specimen stationary is plotted against the potential, a curve which will be called the P/C diagram is obtained, and this is related to the potential/corrosion-rate curve as shown in Fig. 5.

For convenience, negative currents are plotted in Fig. 5 on the positive side but as a broken line. The P/C diagram is therefore a somewhat distorted version of the potential/corrosion-rate diagram.

As a first approximation it is probably safe to assume that the cathodic polarization curve is not appreciably affected by changes in the composition of the alloy, provided that arsenic or other such alloying additions, which may influence the hydrogen-evolution reactions, are not introduced. If this assumption is correct it follows that the P/C diagrams of a series of alloys can form a basis for comparison, and this type of curve has two advantages over the potential/corrosion-rate curves. The curves can be obtained reasonably quickly since it has been found that with the sort of alloys under investigation it was possible to obtain reasonably accurate results in 20% H_2SO_4 by allowing the potential to fall or rise at about 0·35 V/h. The second advantage is that if a minority phase is present, or if the steel is susceptible to intercrystalline corrosion, this is detectable as appropriate loops on the curve,[3] although these possible sources of corrosion are generally too small to be detected in weight-loss measurements.

APPARATUS AND EXPERIMENTAL METHOD

The potentiostat is an instrument which can keep the potential of a working electrode (i.e. the steel under investigation) at any desired potential relative to a standard electrode by supplying it with a polarizing current via an inert electrode and without drawing an appreciable current from the standard electrode. The instruments used in the present work were basically similar to the one described by Roberts,[11] the main modification made being that the potentiostat setting could be altered at a constant rate of 0·35 V/h by means of a suitably geared motor. The ability of the instrument to maintain the potential constant is not very great when it is called on to supply a large current, but since over the most interesting portion of the experiment the instrument has to supply only a minute current of a few microamperes, the potentials can be kept constant to very close limits over the important parts of the curve.

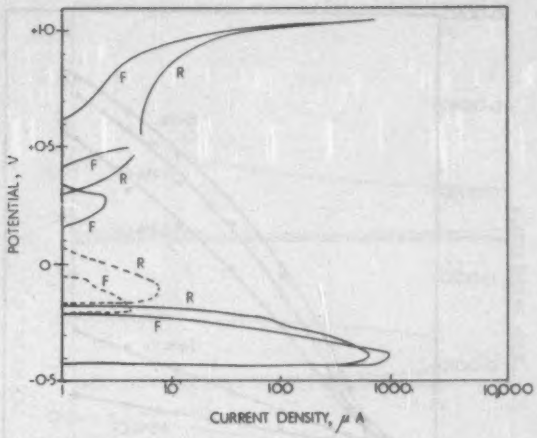


Fig. 7—Typical P/C diagram for an 18–10 Cr–Ni Nb-stabilized steel. Broken lines represent negative currents. Curves marked *F* were obtained as the potential was falling, those marked *R* as it was rising. Experiments started at + 0·5 V

The potentiostats used were coupled to a Honeywell-Brown electronic recorder as shown in Fig. 6 so that both the potential and the current (on three different ranges) could be recorded automatically on the same recorder. The specimens, unless otherwise stated, were ¼-in. dia. cylinders. One end was prepared on 000 emery paper while the cylindrical portion was blanked off with polystyrene lacquer. All tests were carried out in 20% by weight 'Analar' sulphuric acid.

Each run was started at + 0·50 V sat. calomel scale (ignoring liquid junction potentials, quoted values can be converted to the hydrogen scale by adding 0·24 V). After a resting period of 5 min at this potential, the motor operating the potentiostat setting was started and a record kept of potentials and currents. Eventually, when the potential had reached either a suitably high or low value, the motor was reversed and the experiment ended when + 0·5 V was reached again. In other words, curves were obtained both as the potential was falling and rising.

A typical complete P/C diagram for a commercial steel, 18–10–Nb, is shown in Fig. 7 and this is very similar to the sort of curve obtainable with the plain 18–8 steel.[3] Point *B* which has been referred to before occurs at approximately − 0·2 V, which corresponds

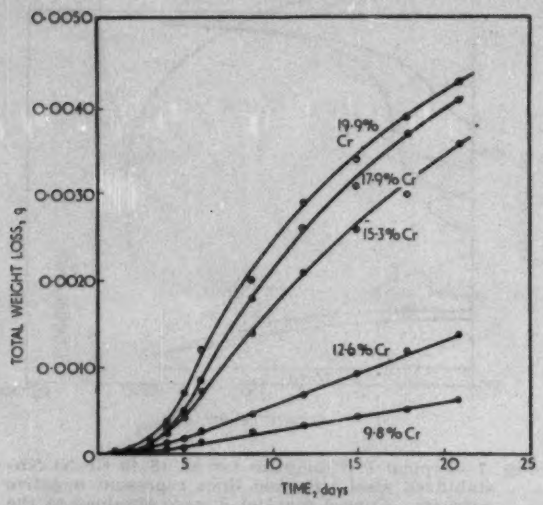


Fig. 8—Corrosion at room temperature of various chromium steels in 65% HNO_3 + 1 g/l. hexavalent chromium. The specimens were about 15 cm^2, and the volume of the solution 80 ml. Nominal Ni content of steels 12% and carbon content 0·05–0·08%

with the sudden drop in potential observed during the breakdown of passivity of these steels.[12]

For the sake of clarity, in all the figures which follow only half the run has been plotted. The curves drawn below + 0·5 V were obtained as the potential was falling and those above + 0·5 V as it was rising. In certain cases there was appreciable hysteresis but this was not sufficient to invalidate the main trend of the results.

RESULTS ON SOME EXPERIMENTAL STEELS

These experiments have been carried out over a period of years and the technique has altered with time. Only some of the more recent experiments carried out in the manner described are reported.

Highly Oxidizing Conditions

As stated before, portion *P* of the curve is the most important if resistance to highly oxidizing conditions is the aim. For theoretical reasons chromium was believed to be the main element in lowering this portion of the curve[1] and a few preliminary curves confirmed this. This appeared surprising because it indicated that chromium, which is so efficient in inducing low corrosion rates to steels in, say, HNO_3, becomes a nuisance in more highly oxidizing solutions such as nitric–chromic acid mixtures. A few conventional corrosion tests on a series of 12% Ni steels in a solution containing 65% HNO_3 and 1 g/l. hexavalent chromium showed that, at room temperature, the low-chromium steels corroded more slowly (Fig. 8). It is interesting to note that there is an induction period, a fact of theoretical interest previously reported by Truman.[13]

Suitable P/C curves are not available for these particular steels but curves on low-chromium steels with 18% Ni, primarily made with a view to HCl resistance, have been obtained more recently and three of these are shown in Fig. 9. The differences in the top portion of the curves (i.e. in portion *P*) at the various chromium levels are obvious and it is interesting to note that the higher-chromium steel is the one which corrodes most rapidly in strongly oxidizing conditions. At the same time, the appreciable change in portion *Q* of the curve must be taken into consideration since the effect of chromium on this portion is the reverse of that on portion *P*; this explains the apparent inconsistency that a high chromium content is an advantage in, say, 65% HNO_3 but not in the more strongly oxidizing solutions containing chromic acid.

Although a considerable number of curves have been drawn, the effect of Ni, Si, Ti, Nb, Al, etc. on this portion is not yet very easily explicable. There have been metallurgical complications which have invalidated much of the work and, since intercrystalline corrosion seems to be practically unavoidable at this end of the scale, any minor effects which are measured may not have meaning.

Resistance to Non-oxidizing Acids containing Air

Sulphuric acid can be regarded as typical in this class and, with the 18–8 steels, the position is shown in Fig. 3. As stated before, the steel can be either passive (*A* intersect) or active (*C* intersect) in this case, and the stability of passivity is probably the most important factor to consider. If at the beginning the specimen is passive but some 'accident,' such as a scratch, occurs on a small portion of it, it will become locally active and the specimen as a whole will then take up a compromise potential[3] while electrolytic currents flow through the solution. Whether passivity survives or not then depends partly on the relative sizes of damaged and undamaged surfaces and partly on the relative sizes of the positive and negative loops of Fig. 5. This is so since the anodic current necessary for again rendering the active steel passive is given approximately by the maximum of the positive loop and the cathodic current, which can be supplied by the passive steel without breakdown, is given approximately by the maximum of the negative loop. Changes in the steel composition which lead to a shift of portion *Q* to the

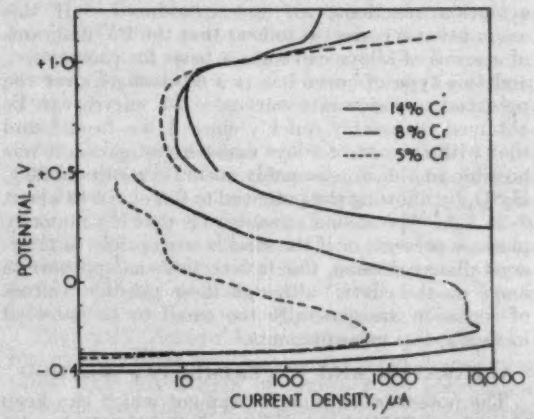


Fig. 9—P/C diagrams for three 18% Ni steels with various chromium contents

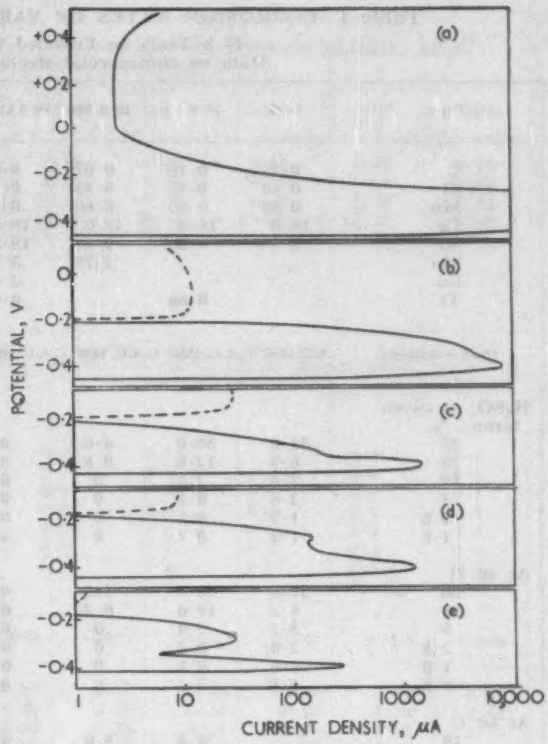
left and R to lower potentials tend to stabilize passivity and so does a shift of portion S to higher potentials. Alternatively, changes in the solution composition which alter the position of the cathodic polarization curve will affect greatly the relative sizes of the positive and negative loops (cf. Fig. 5) and therefore also the probability of passivity breakdown. This is actually found to be the case and the addition to the solution of traces of any of the weak oxidizing agents such as cupric, ferric, or mercuric ions, all of which tend to undergo cathodic reductions at potentials above B (about $-0{\cdot}2$ V calomel for 18–8 type steels), is well known to lead to stable passivity. On the other hand, de-aeration of, say, N-H_2SO_4 leads to the situation shown in Fig. 4 since in the absence of oxygen the only possible cathodic reaction, hydrogen evolution, occurs at a potential below about $-0{\cdot}24$ V on the present scale. This is somewhat lower than the range of passivity for most 18–8 steels (cf. Fig. 7) and passivity is therefore impossible if oxygen and all other oxidizing agents are removed.

To improve the resistance of the steel to this type of condition it is necessary first to increase the size of the negative loop by shifting portion Q to the left and R downwards. Both these effects normally occur if the chromium is increased, as shown by the examples in Fig. 9. At this stage a choice has to be made on metallurgical grounds. Chromium steels can be either austenitic, and must then also have a fair quantity of nickel or other suitable alloy in addition, or they can be mainly martensitic and ferritic and contain little or no nickel.

The phase diagram of the Fe–Cr–Ni steels is such that an increase in chromium beyond 18% calls for a considerable increase in the nickel content beyond 8% if the alloy is to be kept fully austenitic; since the improvement obtainable by increasing chromium beyond 18% is comparatively small this is both an expensive and inefficient way to improve the steel. The alternative would be to reduce the size of the positive loop by raising portion S of the curve; this is best achieved by increasing the nickel alone or, even better, by adding copper to the steels. This is presumably so because both these alloying metals are relatively noble. Of all the other possible alloying additions, most of which have now been tried, only molybdenum seems to have a really marked and interesting effect and, as far as can be seen from the curves so far available, it leads simultaneously to a greater fall in portion R and a greater rise in portion S of the curve than does a corresponding increase of the chromium and nickel contents. The situation is, however, somewhat complicated because of the strong ferrite-forming tendencies of molybdenum which makes it difficult to make really comparable steels.

This particular approach to improvement will not be discussed further because conventional testing showed long ago the beneficial effect of both copper and molybdenum in H_2SO_4. There are many commercial steels available with compositions in the range 18–25% Cr, 18–25% Ni, and with 2–5% of both molybdenum and copper, which, as is well known, are particularly good in H_2SO_4.

The alternative possibility of making martensitic or ferritic steels is metallurgically more complicated.



(*a*) 21·5% Cr
(*b*) 20–3 Cr–Ni
(*c*) 20–3–1 Cr–Ni–Mo
(*d*) 20–3–1 Cr–Ni–Cu
(*e*) 20–3–1–1 Cr–Ni–Mo–Cu

Fig. 10—P/C diagrams for steels based on the 20% Cr composition (broken lines represent negative currents)

At the 18–20% Cr level the iron–chromium alloys, depending on the carbon and nitrogen content, are largely ferritic, but normally there is some small trace of austenite at softening temperature. This on the whole is desirable since a fully ferritic steel would tend to have large grain size. The composition of the austenite is naturally different to that of the ferrite and is probably 3–4% lower in chromium and also probably contains a large proportion of the carbon and nitrogen in the steel. On cooling this to room temperature the austenite may transform to martensite and may also throw out carbides which would further deplete the chromium locally. The result is that, except in very exceptional cases, there will be some very low chromium zones in the steel and these will have corrosion characteristics of their own. The properties of the matrix of 20% Cr steel are consistent with high resistance in H_2SO_4, portion R being very low, but this is spoiled by portions Q and R of the low-chromium regions so that the combined P/C diagram for a 20% Cr steel is as shown in Fig. 10*a*. In this case the maximum of the positive loop was too great to measure and there was no negative loop, indicating that there is no chance of passivity in 20% H_2SO_4. Some improvement can be achieved by

Table I—CORROSION RATES OF VARIOUS STEELS IN SULPHURIC ACID

24 h Tests on Emeried Cylinders (mg/cm²/day)
(Data on commercial steels represent typical results)

Type:	18–8	18–8 Ti	18–8 Mo	18–8 Mo–Cu	20% Cr	20–3 Cr–Ni	20–3–1 Cr–Ni–Mo	20–3–1 Cr–Ni–Cu	20–3–1–1 Cr–Ni–Mo–Cu
C	0·10	0·10	0·07	0·07	0·05	0·07	0·06	0·07	0·06
Si	0·60	0·80	0·30	0·4	0·90	0·47	0·49	0·49	0·42
Mn	0·80	0·80	0·80	0·8	0·52	0·93	1·01	0·86	0·86
Cr	18·0	18·0	18·0	18·0	20·9	19·96	19·92	20·12	20·10
Ni	8·5	9·0	9·5	18·0	0·77	3·04	3·04	3·04	3·04
Mo	...	...	2·75	3·75	...	...	0·88	...	0·82
Cu	...	...	...	2·4	...	...	...	1·00	1·00
Ti	...	0·60	...	0·6	...	...	...	...	...
Heat-treatment:	**A.C. 1050° C**	**A.C. 1050° C**	**A.C. 1050° C**	**A.C. 1050° C**	**A.C. 830° C**	**A.C. 830° C**	**A.C. 830° C**	**A.C. 830° C**	**A.C. 830° C**
H_2SO_4 at room temp., %									
35	33·0	50·0	4·0	0	...	...	...	...	...
20	6·9	12·0	0·5	0	...	127·0	94·9	90·6	20·4
10	3·6	2·0	0	0	...	71·4	60·0	31·2	0·1
5	2·6	0·5	0	0	>75·0	40·0	0·3	9·0	0·1
2·5	1·7	0·1	0	0	>30·0	16·6	0·1	0·6	0
1·0	1·4	0·1	0	0	>15·0	3·6	0·1	0·1	0
At 40° C									
20	37·5	60·0	1·5	0	...	...	...	...	...
10	9·2	10·0	0·2	0	...	...	...	...	0·1
5	3·2	2·0	0	0	...	...	0·1	...	0
2·5	2·0	0·2	0	0	...	...	0	1·4	0
1·0	1·6	0·1	0	0	...	...	0	0·1	0
0·5	1·4	0·1	0	0	...	...	0	0	0
At 60° C									
10	...	20·0	5·0	0	...	...	0	...	...
5	...	10·0	2·0	0	...	...	0	...	0
2·5	8·6	1·0	0·2	0	...	...	0	...	0
1·0	4·1	0·5	0	0	...	...	0	0·1	0
0·5	2·6	0·1	0	0	...	...	0	0	...
0·25	2·0	0	0	0	...	...	0	0	...
At 80° C									
10	...	...	10·0	0·4	...	...	...	...	...
5	...	...	5·0	0·1	...	...	7·7	...	...
2·5	...	5·0	2·0	0·1	...	...	6·6	...	0
1·0	...	1·0	0	0	...	...	0·1	24·6	0
0·5	...	0·5	0	0	...	...	0	0	0
0·25	...	0	0	0	...	...	0	0	...
At B.P.									
1·0	...	...	8·0	2·2	...	...	8·3	...	...
0·5	...	6·0	3·0	0·9	...	...	0·3	14·4	6·4
0·25	...	4·0	1·5	0	...	...	0·3	7·1	1·2

adding, say, 3% Ni to the steel which leads to the formation of a fair amount of austenite at softening temperatures, but austenite presumably having a high chromium content and also probably lower in carbon. The P/C diagram for such a steel is shown in Fig. 10*b* and comparison with Fig. 10*a* shows that there has also been a slight lift of portion *S* due to the Ni addition, but this portion is still not as high as in the 18–8 steels. Mo and Cu have the effects shown in Figs. 10*c* and *d* and their combined effect is seen in Fig. 10*e* in which the duplex nature of the loop is well seen. As might be expected from the position of portion *R* and the presence of a negative loop, some of these steels ought to have reasonable properties, and Table I shows the composition of the steels in Fig. 10 and also some of the results of conventional tests on emeried cylinders. For comparison, data on the more conventional austenitic steels are included. The table shows that it is possible to produce resistant materials based mainly on a ferritic structure and that the results are consistent with the P/C diagrams. These alloys contain less alloying elements than some of the austenitic ones, but from a metallurgical and fabrication point of view the position is somewhat complicated and this type of steel may not be a practical proposition, especially as the steels are very sensitive to variations in the austenite/delta ratio. From a corrosion point of view the fully delta ferritic steels, for which point *B* is well below — 0·3 V, would be very interesting, because this is below the potential at which hydrogen evolution can occur, and therefore such steels may not always have to depend on dissolved oxygen for passivity.

The double peak of Fig. 10*e* is interesting since,

Table II

CORROSION RATES OF SOME 10–12% Cr 10–12% Ni STEELS IN HYDROCHLORIC ACID
24 h Tests on Emeried Cylinders (mg/cm² day)

Cast No.	G.4883	G.3313	G.4886	G.5045	G.5190	G.5191	G.5070	G.5071	G.5228
C	0·06	0·07	0·06	0·09	0·09	0·09	0·08	0·07	0·14
Si	0·16	0·84	0·22	0·51	0·29	0·31	*3·10*	*5·48*	*6·59*
Mn	0·23	0·47	0·23	0·51	1·42	1·43	1·48	1·54	1·44
Cr	11·80	15·27	11·76	11·74	10·10	10·16	10·21	10·33	9·66
Ni	11·85	11·98	15·45	11·50	11·10	10·90	11·13	11·25	11·05
Mo	...	...	...	3·88	6·09	7·95	...		
Cu	...	...	...	...			...		
Ti	...	...	...	...			...		
Others	...	...	...	...			...		
Heat-treatment:	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C
HCl at room temp., %									
20	2·3*	6·5	4·6	1·0*	0·4	0·3	5·6	3·9	1·6
10	0·8	1·1	1·0	1·4*	1·2	0·8	2·1	0·8	0·6
5	0·4	0·8	0·5*	1·6*	0·9	0·5	0·9	1·6	0·4
2·5	0·4	0·7	0·3*	0·8	0·6	0·5	0·5	1·1	0·3
1·0	0·3	0·3	0·1	0·5	0·4	0·3	0·5	0·3	0·4
0·5	0·4	0·5	0·1	0	0·3	0·1	0·5	0·3	0·4
0·25	0·3	0·5	0	0	0·5	0·4	0·5	0·3	0·3
Observations								Partly	Ferritic

Cast No.:	G.4890	G.5193	G.5267	G.5269	G.4932	G.4979	G.5138	G.5140	G.5235	G.5141
C	0·05	0·12	0·08	0·08	0·07	0·10	0·08	0·09	0·10	0·10
Si	0·20	0·62	0·47	0·36	0·40	0·21	0·24	0·17	*6·34*	*4·12*
Mn	0·23	1·72	0·39	0·42	0·32	1·46	0·36	0·36	1·63	1·72
Cr	12·04	11·02	9·90	10·14	11·92	9·98	13·94	11·02	10·08	11·46
Ni	11·70	11·03	11·20	11·30	11·03	11·23	11·45	11·38	11·13	11·55
Mo	...	...	...	...	...	2·21	1·80	...	...	1·80
Cu	2·0	...	...	...	...	2·03	...	2·03	2·00	2·03
Ti	...	2·98	...	...	...	...	...	...	...	...
Others	...		W 5·75	Al 4·30	V 1·82	...	Co 3·01	Co 2·88	Co 3·05	Co 2·88
Heat-treatment:	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C	A.C. 1050 C°	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C
HCl at room temp., %										
20	2·6*	1·4	0·7	17·7	8·2	1·18*	1·2	1·3	0·6	1·5
10	0·7*	0·7	1·0	4·4	1·4	1·0*	1·8	0·5	0·2	0·5
5	0·4	0·3	0·6	3·2	0·5	0·5	1·3	0·2	0·2	0·2
2·5	0·3	0·4	0·5	2·6	0·4	0·3	0·9	0·2	0·1	0·2
1·0	0·3	0·6	0·7	2·3	0·3	0·3	0·5	0·2	0	1·2
0·5	0·3	0·6	0·6	1·2	0·3	0·3	0·3	0·2	0	0·1
0·25	0·3	0·5	0·7	2·5	0·3	0·3	0·8	0·2	0	0·2
Observations		Partly martensitic		Partly ferritic						

Note 1—Except in cases marked * the results are single determination and must be regarded as indicating a trend rather than accurate corrosion rates

Note 2—Lower corrosion rates in 20% HCl than in 10% HCl, especially with high-molybdenum steels such as with G.5045, G.5190, and G.5191, have been observed on many steels and are real and not due to experimental errors

when it is present, there may be two more intersects between the anodic and cathodic curves than in Fig. 3, one of which represents an additional stable corroding potential. If the steel breaks down it can therefore either take up this intermediate potential, at which mainly the lower-chromium phase is corroding, or it can break down to the lower active potential, at which mainly the higher-chromium phase, the delta in this case, is being attacked. If the rate of corrosion of the two phases is very different at either of these potentials the result is what is generally called selective corrosion. Naturally a somewhat similar phenomenon can take place at the top of the P/C diagram. This difference in corrosion rate between phases at suitable potentials is made use of in metallography by using etching reagents with suitable redox potentials. The potentiostat can naturally also be used for this purpose.

Resistance under Reducing Conditions

If the situation is as in Fig. 4, either because there

Table III

CORROSION RATES OF SOME 18–19% Ni STEELS AND ONE 30% Ni STEEL IN HYDROCHLORIC ACID
24 h Tests on Emeried Cylinders (mg/cm²/day)

Cast No.:	G.5207	G.5021	G.5023	G.5355	G.5499	G.5162	G.5391	G.5836
C	0·07	0·08	0·07	0·06	0·08	0·05	0·07	0·007
Si	0·25	0·24	0·36	0·64	0·54	0·45	0·50	0·39
Mn	0·34	0·44	0·52	0·47	0·42	0·50	0·41	0·45
Cn	4·59	7·86	13·90	8·11	7·86	7·98	8·14	3·78
Ni	18·88	19·02	19·28	18·20	18·55	18·20	18·10	30·40
Mo	...	...	...	6·01	1·99	1·93	2·50	7·20
Cu	...	...	...	2·03	5·95	1·98	2·50	3·00
Heat-treatment:	A.C. 1050° C	A.C. 1050° C	A.C. 1050° C			A.C. 1050° C	A.C. 1150° C	A.C. 1150° C
HCl at room temp., %								
20	1·6*	1·5*	4·0		...	0·3*	...	...
10	0·6	0·5	0·7		...	0·2*	...	...
5	0·4	0·3	0·5	...	...	0·2*	...	...
2·5	0·3	0·3	0·3	...	...	0·2*	...	...
1·0	0·2	0·1	0·2	...	...	0·1	...	...
0·5	0·3	0·1	0·2	...	...	0·1	...	...
0·25	0·3	0·1	0	...	...	0·1	...	...
HCl at 60° C, %								
20	...	...	...	7·0	39·3	3·6	29·8	2·2
10				2·8	2·6	2·1	3·4	1·6
5				2·5	1·3	1·1	1·0	1·4
2·5				2·1	1·0	1·1	1·1	1·2
1·0				1·0	0·8	0·9	0·8	1·0
0·5				0·7	0·7	0·8	0·6	0·8
0·25				0·6	0·6	0·7	0·5	0·7
Observations	P/C diagram in Fig. 9	P/C diagram in Fig. 9	P/C diagram in Fig. 9	Inter-crystalline corrosion in 20% acid suspected. P/C diagram in Fig. 12	Inter-crystalline corrosion in 20% acid caused grains to fall out. P/C diagram in Fig. 12	Similar steel with 0·009% carbon gave no improvement	Inter-crystalline corrosion in 20% acid caused grains to fall out. P/C diagram in Fig. 13	

Note—Except in cases marked * the results are single determination and must be regarded as indicating a trend rather than accurate corrosion rates.

is no oxygen or because the acid is so reactive (e.g. HCl) or hot that the whole potential/corrosion-rate curve is moved to the right, the only way to decrease the corrosion rate is to move portion *S* as high as possible. Naturally this can be done by using alloys based on the noble and semi-noble metals such as nickel and copper, but an effort has now been made to see to what extent this could also be done on an iron-based alloy.

The Fe–Cr–Ni system again proved interesting and is the only one which will be discussed now. After a preliminary study of the system it was decided to concentrate on alloys based on the following compositions: (*a*) 10–12% Cr, 10–12% Ni; (*b*) 8% Cr, 18% Ni; and (*c*) 0–4% Cr, 26–30% Ni. Each of these basic compositions had advantages both from a corrosion and a metallurgical point of view, but all three seem to have one thing in common. They all have an M_s near room temperature and they represent the lowest-chromium austenitic alloys at these particular nickel levels. Chromium on the whole tends to lower portion *S*, as might be expected, but so does martensite, so that sufficient chromium must be added to keep the composition austenitic. This can be seen to a certain extent in Fig. 9 but is more obvious in Fig. 11, in which is shown the effect of chromium on the corrosion of a series of 18% Ni steels in 5% and 10% HCl.

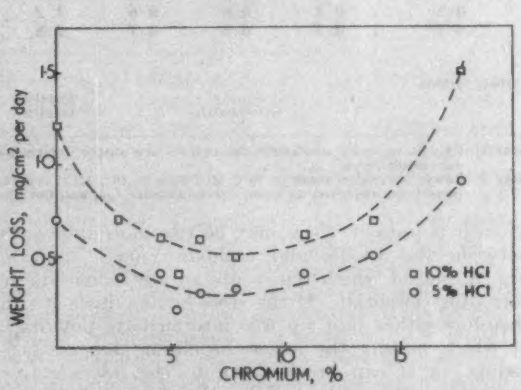


Fig. 11—Corrosion rate in 5% and 10% HCl at 20° C with a series of 18% Ni steels with various chromium contents

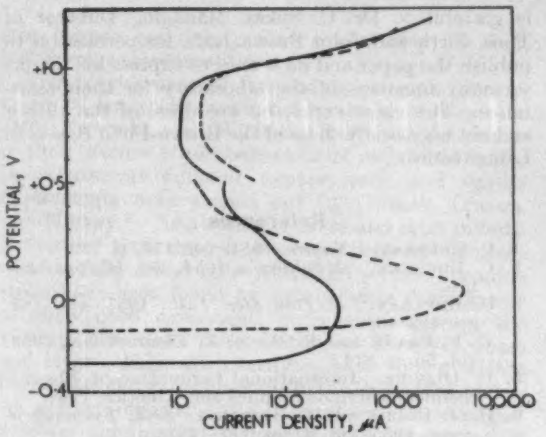


Fig. 12—P/C diagram for a 8–18–6 Cr–Ni–Mo steel and of a 8–18–6 Cr–Ni–Cu steel (broken line)

The 10–12 Cr–Ni series is interesting since it is possible to make large additions of ferrite-forming elements to this composition without producing delta ferrite. Steels with, for instance, 5–6% Si were made, forged, and tested, but on the whole the resistance of this family of steels to HCl was not adequate to make them of practical interest. A few typical examples of some of the more resistant alloys tested are given in Table II. The Mo–Cu combination has again given the best results but there is a trend towards improvement as the number of alloying elements is increased.

The other two families of alloys were more resistant than the 10–12 series as shown in Table III and some of the casts have a reasonably wide range of usefulness in this acid as might have been expected from P/C diagrams such as those shown in Figs. 12 and 13. It is necessary, however, to exercise some care in the interpretation of these curves in this particular case, especially when one of the alloying elements, such as copper, is being replated on the surface. This may affect the cathodic polarization curve appreciably.

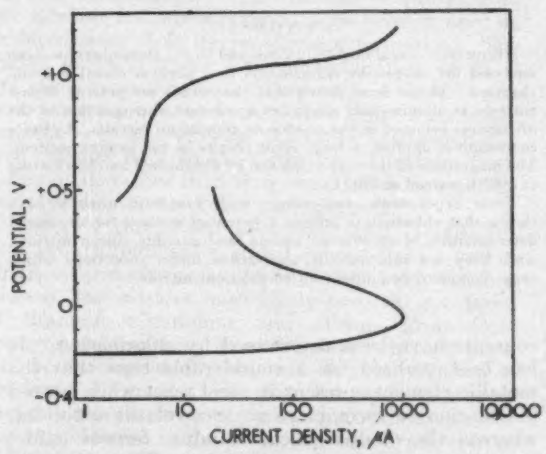


Fig. 13—P/C diagram for a low-carbon 8–18–2–2 Cr–Ni–Mo–Cu steel

Table IV

CORROSION OF COMMERCIAL STEELS IN HYDROCHLORIC ACID, mg/cm²/day
(Typical Results)

Type:	18–8	18–8 Ti	18–8 Mo	18–18 Mo–Cu
% HCl at room temperature:				
20	82·5	48·9	18·9	0·8
10	5·7	5·0	9·7	0·4
5	2·5	3·5	2·8	0·2
2·5	1·7	3·0	1·0	0
1	1·7	1·5	0	0
0·5	1·0	0·1	0	0
0·25	0	0	0	0
at 40° C:				
20	...	137·9	165·7	2·5
10	...	14·4	55·5	1·6
5	...	6·3	14·3	1·2
2·5	...	5·5	5·4	1·3
1·0	3·0	1·3	0·5	0
0·5	1·7	1·0	0	0
0·25	1·4	0·9	0	0
at 60° C:				
20	...	...	...	8·0
10	...	...	...	5·0
5	...	...	73·9	4·0
2·5	...	...	20·1	2·0
1·0	...	3·7	1·0	0·1
0·5	...	3·2	0·1	0
0·25	...	1·0	0	0

What is obvious, however, is that the whole positive loop for these alloys occurs at a much higher potential than for 18–8 steels. This explains the rather slow rate of corrosion of the present series of steels under active conditions, and at the same time, since the P/C diagrams have no negative loop, it is possible to explain why, unlike some of the 18% Cr steels (Table IV), no passivity in dilute HCl is obtained with these steels.

Table III may, at first sight, give a rather optimistic picture about the practical side of the problem and also about the progress made. There are two main difficulties with these alloys: intercrystalline corrosion and stress corrosion. The intercrystalline corrosion effect unfortunately was only recognized towards the end of this work, but as the steels became better it was noticed that, in certain cases, the weight loss was mainly due to grains falling out rather than to corrosion itself. This is promising since it indicates that if intercrystalline corrosion can be overcome the alloys would be appreciably better than indicated in Table III. The difficulty is that at present it is not clear to what this intercrystalline corrosion is due. It can be controlled by going to very low carbon contents (cf. Table III), but these low-carbon steels are not a practical proposition. The stress corrosion difficulty was also only recognized lately and is more serious. The steels, as already stated, are very near the austenite/martensite boundary so that any slight cold work causes them to transform to martensite. As with the more normal austenitic compositions this leads to rapid stress-corrosion cracking,[14] but it was rather unexpected that it should take place in HCl. If the presence of martensite is, as suspected, respons-

ible for the cracking, all the present three families of steels are of no further practical interest.

SUMMARY AND DISCUSSION

The purpose of this paper is to outline a technique which can be used to study the corrosion properties of acid-resistant alloys using steels as an example. As stated previously, the technique used is not necessarily the best one for any particular case.

A number of alloys of non-conventional composition have been mentioned but it is important to appreciate that a great many factors have to be taken into consideration before it is possible to produce a useful new alloy and the only purpose in discussing these was to show how the present technique can be used in practice during development work.

The work shows that with base metals there is no such thing as an intrinsic acid resistance and that it is not possible to make a straightforward comparison between steels in this respect. It is possible, however, to define a number of properties such as 'range of passivity,' 'stability of passivity,' etc. and to obtain a fair indication of these properties by comparing either the 'potential/corrosion-rate' or 'potential/current' diagrams of various alloys. These curves are obtained with the aid of a potentiostat in the manner described in the paper.

Acknowledgments

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The Effect of Nitrides in Silicon Iron on the Determination of Oxygen by Chlorination, and the Possible Direct Determination of Aluminium Nitride

By F. J. Armson, M.Sc., A.R.I.C., and H. L. Bennett

SYNOPSIS

Silicon iron containing 4% silicon and 0·3% aluminium has been analysed for oxygen by chlorination in a vertical closed reaction chamber. It has been shown that the oxides are present almost entirely as alumina and silica, but a substantial proportion of the nitrogen is retained in the residue as aluminium nitride. Unless a correction is applied, a large error results in the oxygen content. The magnitude of the correction can be diminished by chlorinating at 600° C instead of 500° C.

These experiments and others with synthetic nitrides have shown that chlorination affords a potential method for the direct determination of aluminium nitride (and possibly silicon nitride), since they are substantially unattacked under conditions which cause complete decomposition of titanium nitride. 1445

Introduction

THE PRESENCE of oxygen and nitrogen in silicon irons such as Stalloy (4% Si) is known to have deleterious effects on their electrical properties. The magnitude of these effects is likely to be dependent on the state of combination of the oxygen and nitrogen with other elements. For this reason, methods which determine the actual oxides and nitrides present are more valuable than techniques giving the total amounts of oxygen and nitrogen, e.g. vacuum fusion. The work described in this paper is part of a lengthy programme in progress in the Chemistry Department of the G.K.N. Group Research Laboratory, for the development of suitable techniques for determining these and other non-metallic compounds.

The individual oxides (and hence the total oxygen content) have been determined by chlorination. It has been realized for a considerable time that the metallic elements present in steel react when heated in chlorine to form more or less volatile chlorides, whereas the oxides (silica, alumina, ferrous oxide, manganous oxide, and combinations of these) remain virtually unattacked. (Depending on the conditions,

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free ferrous and manganous oxides may, in fact, suffer some decomposition.)

The development of this simple principle into an accurate analytical method has not been easy. In 1929 Wasmuht and Oberhoffer[1] reported the results of their studies of the behaviour of individual oxides in chlorine at different temperatures, and similar experiments were carried out by Colbeck, Craven, and Murray.[2] As a result of these and later investigations,[3, 4] total oxygen determinations by chlorination on fully killed mild steels and certain low-alloy steels have been found by collaborative examination to show good agreement, in general, between the vacuum fusion and other methods. However, these and later collaborative analyses have shown serious inconsistencies in the amounts of the individual oxides. As already reported,[5] the Laboratory has developed a novel chlorination technique with the object of overcoming the difficulty, and the results so far obtained on fully killed mild steels appear satisfactory with regard both to total oxygen and to individual oxide contents.

In extending the method to silicon irons, an important source of error has been discovered, hitherto unreported. This is the survival of substantial amounts of unchanged aluminium nitride after chlorination. Owing to the stability of this compound, the amount of aluminium subsequently determined in the residue will be considerably higher than that due to aluminium oxide alone. The oxygen content finally calculated from this figure will, therefore, be correspondingly higher than the true value. It has been found that a correction can be simply applied to give the true oxygen content, and that there is a strong possibility by this method of directly determining aluminium nitride and, perhaps, silicon nitride in the steel.

BEHAVIOUR OF NON-METALLIC COMPOUNDS IN CHLORINE

When applying the chlorination technique to the determination of oxygen, nitrides are generally considered to be broken down to give the corresponding chloride and nitrogen.[6] In the case of silicon iron, the nitrides one would expect to be present may be deduced from their free energies of formation. The values given in Table I for a temperature of 25° C are taken from the data of Pearson and Ende.[7] At processing temperatures, the values differ from these, but the sequence remains the same. Although the free energies refer to the formation of nitrides from pure metals rather than their equilibrium in a parent metal phase, the list forms a useful guide.

Since, in the silicon irons examined, aluminium had been intentionally added (about 0·3%) and a small amount of titanium (about 0·01%) is invariably present, the nitrides most likely to occur are those of titanium, aluminium, and silicon. From free-energy considerations, it can be shown that all these will be decomposed by chlorine when equilibrium is reached. However, this may be a slow process and published data on the behaviour of these nitrides towards chlorine in the range 300–600° C are scarce.

The little evidence available on the reactions of aluminium nitride with chlorine is conflicting. In the course of a collaborative examination of a series of alloy steels, three aluminium-bearing samples (0·15–0·5% Al) were analysed for oxygen by several procedures, including a chlorination method.[4, 8] The results indicated that aluminium nitride was decomposed by chlorine, whereas it appeared to remain in the residue left after alcoholic iodine extraction.[9] Klinger and Koch[6] also consider that aluminium nitride is decomposed. On the other hand, Flament[10] has shown that aluminium nitride is stable when chlorinated for 2 h at 350° C.

Titanium nitride is said to be stable towards chlorine at 270° C,[11] but is decomposed at about 350° C.[12] Klinger and Koch have also reported decomposition below 400° C.[6]

It has not been possible to find any corresponding information about silicon nitride in the literature.

The position of the other non-metallic compounds during chlorination is clearer, and none seems likely to affect the results in the case of silicon irons. The sulphides decompose, forming volatile sulphur monochloride which in large amounts may cause a loss of iron and manganese oxides.[1] The decomposition of phosphides may lead to reduction of these oxides, but the oxygen is retained in the form of phosphorus pentoxide, which can be determined during the analysis. Of the carbides present, all decompose, forming the corresponding chloride and carbon.

If any nitrides remain undecomposed after chlorination, the amounts of the metals subsequently determined in the residue will be considerably higher than those due to the oxides alone. The oxygen content finally calculated from these figures will, therefore, be correspondingly higher than the true value. It is clear that the published data leave the matter in a very uncertain state. In view of the importance of reliable oxygen determinations, a programme of experimental work has been undertaken to investigate the behaviour of the nitrides towards chlorine, including studies on both silicon-iron samples and synthetic nitrides.

Table I

STANDARD FREE ENERGY OF REACTION
$2M + N_2 = 2MN$ (25° C)

Nitride	Standard Free Energy, kcal/g-mol of nitrogen
Titanium (TiN)	− 147
Aluminium (AlN)	− 130
Silicon (Si_3N_4)	− 78
Vanadium (VN)	− 72
Manganese (Mn_3N_2)	− 47
Chromium (Cr_2N)	− 41
,, (CrN)	− 37
Iron (Fe_4N)	+ 2

EXPERIMENTAL WORK

Chlorination Experiments on Steel Samples

Material—Two casts of aluminium-bearing silicon irons were selected, similar except for the titanium

Table II—COMPOSITIONS OF SILICON IRONS

Cast	C, %	Si, %	Al, %	Ti, %	N, %	S, %	P, %	Mn, %	Ni, %	Cu, %	Sn, %
A	0·055	4·04	0·34	0·008	0·005	0·014	0·026	0·07	0·045	0·064	0·044
B	0·050	4·16	0·36	0·013	0·005	0·010	0·024	0·10	0·049	0·058	0·040

contents, which differed markedly. The compositions are given in Table II.

Samples—These were produced from sheet bar by slow milling, each measuring about $\frac{7}{8}$ in. × $\frac{5}{8}$ in. × $\frac{1}{16}$ in. and weighing approximately 14 g. They were stored under ether until just before chlorination.

Chlorination—The detailed technique has been published.[5] The sample was introduced into the vertical closed-glass reaction chamber, which was first evacuated and then filled with chlorine. The temperature of the sample was gradually raised to either 500° or 600° C, more chlorine being added as necessary. (These temperatures are higher than sometimes used, but they have the advantage of yielding purer residues. The results show that any decomposition of the oxides was negligible.) The reaction appeared to be complete after 6–7 h, but heating was continued for 20 h in all.

In some cases the residue was analysed directly for nitrogen or examined by X-ray diffraction, but generally it was purified as follows.

Purification of the Residue—The cycle used was based on the recommendations of Short *et al.*[5] For oxygen determinations, the full treatment was as follows. The residue was transferred to a filter pad with 50 ml of cold water and washed with successive 20-ml portions of boiling water, boiling 3% sodium carbonate solution, boiling water, cold water, cold 5% (v/v) hydrochloric acid, cold water, and finally with 2 ml boiling water. After ignition, the residue was analysed for aluminium, silicon, iron, and manganese by a procedure based on published methods.[13]

Comparable washing treatments in centrifuge tubes were in some cases given instead, so that these residues could be analysed for nitrogen or examined by X-ray diffraction.

Chlorination of Synthetic Nitrides

Samples of titanium, aluminium, and silicon nitrides were subjected to the action of chlorine at various temperatures and the amount of decomposition determined.

Determination of Total Nitrogen and Titanium Nitride

The total nitrogen and titanium nitride present in the chosen casts was determined so that certain calculations could be made concerning the amount of aluminium nitride present.

The total nitrogen was determined using the procedure recommended by the B.I.S.R.A. Electrical Sheet Analysis Sub-committee.[14] The silicon-iron sample was dissolved in sulphuric acid; this was followed by a fuming treatment, addition of excess alkali, and titrimetric measurement of the ammonia liberated by distillation. Nitrogen in the chlorination residues was determined by direct fuming with concentrated sulphuric acid and potassium sulphate, followed, as before, by addition of excess alkali and titrimetric measurement of the ammonia liberated by distillation.

For the determination of titanium nitride in silicon iron, four 5-g portions were treated with hot 5% sulphuric acid. The residues were separated by centrifuging and extracted with a further quantity of hot 5% sulphuric acid. The resulting residues were then twice extracted with hot 10% potassium cyanide solution. The residues finally obtained were used, firstly, for titanium analysis (absorptiometrically using hydrogen peroxide, following a bisulphate fusion) and, secondly, for X-ray examination, to confirm the presence of titanium nitride, to detect any other titanium compounds (if present), and to obtain lattice-parameter data. Collaborative work

Table III—ANALYTICAL RESULTS OF CHLORINATION EXPERIMENTS

Cast	Treatment	N, %	Ti, %	Al, %	Si, %	Fe, %	Mn, %
A	After chlorination at 500° C but no washing	$0{\cdot}004_2$	...	...	...	...	...
,,	After chlorination at 500° C and washing	$0{\cdot}003_7$	n.d.	$0{\cdot}010_6$	$0{\cdot}000_7$	$0{\cdot}000_4$	trace
B (Area 1)	After chlorination at 500° C and washing	$0{\cdot}002_4$	n.d.	$0{\cdot}006_7$	$0{\cdot}001_0$	trace	n.d.
B (Area 2)	After chlorination at 500° C and washing	$0{\cdot}002_3$	n.d.	$0{\cdot}006_1$	$0{\cdot}000_4$	n.d.	n.d.
,,	After chlorination at 600° C and washing	$0{\cdot}001_1$	n.d.	$0{\cdot}004_3$	$0{\cdot}000_6$	n.d.	n.d.

n.d. = not detected

Table IV

DECOMPOSITION OF THE NITRIDE AFTER 20h CHLORINATION

Temperature, °C	Sample Weight, g	Loss in Nitrogen, %
500	0·020	17
500	0·240	25
600	0·025	33

Note: It is possible that local temperatures reached were higher than those measured, owing to the reaction of the unchanged metal in the sample with chlorine.

by the B.I.S.R.A. Electrical Sheet Analysis Sub-committee, to be published in due course, has confirmed this technique as a satisfactory method of concentrating the titanium nitride present in silicon iron, along with some of the aluminium nitride.

RESULTS

Chlorination Experiments on Steel Samples

The analytical results are shown in Table III, all the figures being expressed as percentages of the original silicon iron.

The X-ray diffraction photographs revealed the presence of aluminium nitride in both the washed and unwashed residues. The aluminium nitride lines were unaffected when the residue was washed with saturated sodium bicarbonate solution, claimed by Beeghly[15] to dissolve aluminium nitride. The patterns of silicon and titanium nitrides were not observed.

Chlorination of Synthetic Nitrides

Aluminium nitride—The sample, prepared by direct nitriding of aluminium, contained as impurities substantial amounts of alumina and unchanged metal. The X-ray pattern agreed with the data in the A.S.T.M. Index for aluminium nitride. The extent of decomposition of the nitride after 20 h chlorination at 500° and 600° C is shown in Table IV.

Titanium nitride—The sample gave an X-ray pattern corresponding to pure TiN with a lattice parameter of 4·237 Å. This compares well with the value given by Hume-Rothery *et al.*[16] of 4·233 Å. After chlorination at 500° C for 20 h, 94% was volatilized, leaving a residue free from nitrogen.

Silicon nitride—The sample, prepared from the elements at a temperature of about 1500° C, was supplied by Dr. E. T. Turkdogan of B.I.S.R.A. The X-ray pattern was in fair agreement with that given in the A.S.T.M. Index for Si_3N_4 and contained nearly the theoretical amounts of silicon and nitrogen. It was unaffected by chlorination for 20 h at 500° C.

Table V

RESULTS FOR TOTAL NITROGEN

Cast	Nitrogen, %	
	Chemical	Vacuum Fusion
A	$0·005_0$	...
B	$0·005_2$	$0·004_5$

Table VI—RESULTS FOR TITANIUM

Cast	Titanium, %	
	Residue, as Ti(N,C)	Sample
A	$0·005_2$	0·008
B	$0·012_5$	0·013

Determination of Total Nitrogen and Titanium Nitride

The results for total nitrogen are shown in Table V, which includes a comparative result obtained by the vacuum fusion method.

In the case of the titanium nitride determination, the X-ray diffraction photograph of the residue revealed a pattern similar to that of titanium nitride but with a lattice parameter of 4·26 Å, compared with 4·235 Å for pure titanium nitride. This indicates that the titanium nitride is in the form of a solid solution with carbide (Ti(N,C)), containing about 70% of titanium nitride. In the case of cast *A*, aluminium nitride was identified, but it was not positively identified in the cast *B* residue. (This type of extraction at best partially decomposes the aluminium nitride.) No other patterns were identified. The amounts of Ti combined as carbonitride and initially present are shown in Table VI, both calculated as percentages of the original silicon iron.

DISCUSSION AND INTERPRETATION OF RESULTS

Effect of Aluminium, Titanium, and Silicon Nitrides on the Determination of Oxygen

The results shown in Table III, together with the X-ray evidence, clearly show that failure to correct for the presence of aluminium nitride in the chlorination residue will lead to high results for total oxygen. The aluminium nitride in the residues is virtually unaffected by the washing treatment with sodium carbonate and hydrochloric acid. While it is true that synthetic nitrides may differ in reactivity towards chlorine from those occurring in steels, owing to differences in their state of sub-division or in heat-treatment, the evidence in Table IV supports that from the chlorination of the steels.

The results, therefore, confirm those of Flament, who found synthetic aluminium nitride to be stable towards chlorine, and are in disagreement with other workers who consider it to be completely decomposed.

It is also clear that the magnitude of the error introduced can be reduced by chlorination at a temperature of 600° C. The use of higher temperatures still, so as to eliminate nitrogen completely from the residue, is inadvisable in a glass apparatus. While higher temperatures could be reached in a reaction chamber made, for example, of quartz, the controlling factor will be the stability of the oxides, since these may be attacked at the temperature necessary to decompose all the aluminium nitride.

Another approach to the problem is to give a more

drastic treatment to the residue, such as washing with boiling 20% potassium hydroxide solution. This rapidly decomposes aluminium nitride, but the stability of the oxides under such conditions has not been studied.

Titanium nitride (and carbide) are completely decomposed during chlorination at 500–600° C and do not interfere with the oxygen determination. Titanium dioxide, although stable in chlorine at these temperatures, has never been detected by the authors in residues after chlorination.

Silicon nitride appears to be stable towards chlorine, under some conditions at least. The experiments on the synthetic nitride leave no doubt about the stability of this substance when it has been prepared at high temperatures. Our results have produced no evidence for the presence of silicon nitride in silicon iron containing 0·3% aluminium, and its presence in such material seems unlikely.

One would expect that a more likely source of silicon nitride would be silicon iron containing aluminium at the 0·01% level, and Sloman has reported its identification in a silicon iron of this type as well as its stability during chemical treatment.[17] On the other hand, recent work has indicated that it may in some circumstances occur in a relatively reactive form.[18] We have not so far encountered silicon nitride in the limited number of experiments carried out on silicon iron low in aluminium. Should silicon nitride be present, it would probably give rise to high oxygen figures. A tentative method of safeguarding against this would be by regular X-ray examinations and, if silicon nitride were detected, by determining the amount present by analysing for total nitrogen using vacuum fusion and subtracting that combined as aluminium nitride.

In the case of a silicon iron containing 0·3% aluminium, the oxygen can be accurately determined from the analysis of *two* residues as follows. The first is used for the determination of aluminium, silicon, iron, and manganese, which are expressed as their respective oxides; in addition, a test for titanium is carried out as a precautionary measure. The second residue is analysed for nitrogen. The oxygen content is calculated from the expression:

$$\text{Oxygen (\%)} = 0{\cdot}47((Al_2O_3\,\%) - 3{\cdot}64\,(N\,\%)) + 0{\cdot}53\,(SiO_2\,\%) + 0{\cdot}22\,(FeO\,\%) + 0{\cdot}23\,(MnO\,\%)$$

(Iron and manganese oxides have seldom been found by the authors in silicon iron.)

The corrected results, comparative vacuum-fusion analyses, and the magnitude of the correction are shown in Table VII, where all percentages refer to the sample and not to the residue.

It is clear that excellent agreement with the vacuum-fusion value is obtained in the case of cast *B*, and the results as a whole are strong evidence of the importance of the aluminium nitride correction.

Possible Direct Determination of Aluminium and Silicon Nitrides by Chlorination

From the metallurgical point of view, it is important to know the form in which nitrogen exists in silicon iron, and the Chemistry Department of the G.K.N. Group Research Laboratory has been working on the solution to this problem for some time. A method for determining the titanium nitride has been evolved and the presence of aluminium nitride clearly established. So far, silicon nitride has not been found in any of the material examined and the possibility of the presence of any other nitrides seems remote. Thus it can be argued that, if the titanium nitride and total nitrogen in the steel can be determined, any difference must be due to nitrogen in the form of aluminium nitride. (This only applies if the amount of nitrogen in solution is negligibly small.)

A method relying on differences between such small amounts is open to substantial errors, and it is desirable to have a direct technique for the specific determination of aluminium nitride. Beeghly's *ester halogen* extraction method[19] enables the stable nitrides to be concentrated, but it is not specific for individual nitrides.

The experimental results clearly show that titanium nitride can be decomposed by chlorination, leaving the bulk of the aluminium nitride as well as synthetically prepared silicon nitride unattacked. Since, in the residues examined from silicon iron containing 0·3% Al, no evidence for the presence of silicon nitride has been found, the residual nitrogen must be present almost entirely as aluminium nitride. The question that arises is whether this forms the basis for a specific quantitative method for the determination of aluminium nitride. The data on the synthetic nitride in Table IV, as well as the drop in nitrogen content when chlorinating at 600° C compared with 500° C (Table III), show that the reaction

Table VII

CORRECTED RESULTS FOR OXYGEN AND COMPARATIVE VACUUM-FUSION ANALYSES

Constituent	Cast *A*	Cast *B* (Area 1)	Cast *B* (Area 2)	
			500° C	600° C*
Correction for Aluminium Nitride				
Al in residue (total), %	$0{\cdot}010_6$	$0{\cdot}006_7$	$0{\cdot}006_1$	$0{\cdot}004_3$
N " " " %	$0{\cdot}004_0$	$0{\cdot}002_4$	$0{\cdot}002_2$	$0{\cdot}001_1$
Al equivalent to N, %	$0{\cdot}007_7$	$0{\cdot}004_6$	$0{\cdot}004_2$	$0{\cdot}002_1$
Al equivalent to O (by difference), %	$0{\cdot}002_9$	$0{\cdot}002_1$	$0{\cdot}002_0$	$0{\cdot}002_2$
Calculation for Oxygen				
Oxygen present as Al_2O_3, %	$0{\cdot}002_8$	$0{\cdot}001_9$	$0{\cdot}001_8$	$0{\cdot}002_0$
Oxygen present as SiO_2, %	$0{\cdot}000_7$	$0{\cdot}001_1$	$0{\cdot}000_5$	$0{\cdot}000_4$
Oxygen present as FeO, %	$0{\cdot}000_2$	n.d.	n.d.	n.d.
Oxygen present as MnO, %	n.d.	n.d.	n.d.	n.d.
True Total Oxygen Content	$0{\cdot}003_5$	$0{\cdot}003_9$	$0{\cdot}002_2$	$0{\cdot}002_4$
Oxygen Content by Vacuum Fusion	...	$0{\cdot}002_5$ $0{\cdot}003_0$	...	...
Total Oxygen Content Omitting Nitrogen Correction	$0{\cdot}010_2$	$0{\cdot}007_0$	$0{\cdot}005_9$	$0{\cdot}004_2$

* one determination only n.d. = not detected.

$$2\,AlN + 3\,Cl_2 \rightarrow 2\,Al\,Cl_3 + N_2$$

proceeds at an appreciable rate at 600° C. At 500° C, the data on the synthetic nitride results indicate the start of decomposition, but the data given in Table VIII strongly suggest that this is not an important factor in silicon irons of the type examined. Here the amount of nitrogen left after the titanium has been satisfied (Tables V and VI) is compared with that found in the chlorination residue (Table III).

The agreement found between the two sets of results is so striking as to suggest that aluminium nitride in silicon iron is virtually unattacked at 500° C and that the direct determination of aluminium nitride is possible. The number of determinations of aluminium nitride has been few and, unlike the method for titanium nitride, this technique has not yet been confirmed by collaborative work in other laboratories. These statements, therefore, can only be regarded as tentative.

If further work shows decomposition of the nitride to be a more serious problem than these results indicate, the chlorination may have to be conducted at a lower temperature or for a shorter time, or both.

In a similar way, a steel containing nitrogen in the form of titanium and silicon nitrides could probably be chlorinated (e.g. at 500° C) so as to cause complete decomposition of titanium nitride, leaving silicon nitride in the residue. Further, a scheme for the determination of a mixture of titanium, aluminium, and silicon nitrides in a steel may be feasible using chlorination followed by selective decomposition with sodium hydroxide.

CONCLUSIONS

(1) Most of the aluminium nitride present in silicon iron is retained in the residue obtained after chlorination for 20 h at 500° C. Titanium nitride and carbide, present in solid solution, are completely decomposed.

(2) The presence of aluminium nitride causes a considerable error in the conventional method of calculating the total oxygen content. In order to correct for this, the nitrogen in the residue must be determined and the amount of aluminium required to combine with it found. The difference between this and the total aluminium in the residue gives the true amount of aluminium in combination as aluminium oxide.

Table VIII

RESULTS FOR NITROGEN PRESENT AS ALUMINIUM NITRIDE

Constituent	Cast *A*	Cast *B*
Total N (chemical)	0·005₀	0·005₂
,, N (vacuum fusion)	...	0·004₅
Mean N content	0·005₀	0·004₉
Titanium in residues	0·005₃	0·012₅
Equivalent N in TiN – TiC solid solution	0·001₁	0·002₅
Remaining N (by difference)	0·003₉	0·002₄
N in chlorination residue	0·004₀	0·002₄

(3) The following expression gives the true oxygen content, a nitrogen correction term being included:

$$\text{Oxygen (\%)} = 0{\cdot}47\ (\text{Al}_2\text{O}_3\,\%) - 3{\cdot}64\ (\text{N}\,\%)) + 0{\cdot}53\ (\text{SiO}_2\,\%) + 0{\cdot}22\ (\text{FeO}\,\%) + 0{\cdot}23\ (\text{MnO}\,\%)$$

(4) The magnitude of the error is less at 600° C, at which temperature the oxides are still unaffected by chlorine. This is the temperature that should be used for oxygen determinations.

(5) Application of the correction shows that the oxygen in the silicon irons examined (4% Si, 0·3% Al) is distributed almost entirely between alumina and silica. A little iron oxide may be present.

(6) Chlorination at 500° C offers a means of separating titanium nitride from aluminium nitride (and possibly silicon nitride), and the evidence available strongly suggests that the determination of aluminium nitride is possible by the chlorination technique.

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The Routine Determination of Oxygen in Steel using a Carrier-gas Fusion Technique

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SYNOPSIS

A method is described for determining oxygen in steel whereby the sample is melted in a carbon crucible; the carbon monoxide evolved is extracted by a streaming carrier gas and not by vacuum pumps, as in the well known vacuum-fusion procedure. A determination may be made within 15 min with a standard deviation of about 0·0016%.

The method is suitable for use within a steelworks control laboratory since the equipment required is inexpensive, it can be operated and easily repaired under works conditions, and means are provided for the introduction of individual samples during operation. 1512

Introduction

THE VACUUM-FUSION method for the determination of oxygen in steel has been established as an accurate and reliable method for many years. In principle, an intimate contact is made between the oxygen within the sample and carbon atoms at a temperature high enough to cause the rapid formation of carbon monoxide. Vacuum pumps are used to reduce the partial pressure of carbon monoxide in the melting chamber to negligible values, thus ensuring the quantitative conversion of the oxygen to carbon monoxide; at the same time the latter is concentrated in a suitable vessel for its final measurement.

In spite of its reliability, the vacuum-fusion method has not been generally adopted by steelworks laboratories. This is mainly because the apparatus is expensive and fragile, and requires personnel trained in high-vacuum techniques. A method for determining total oxygen which overcomes these disadvantages would be of special interest to steelworks laboratories, particularly those engaged in the day-to-day control of steel quality.

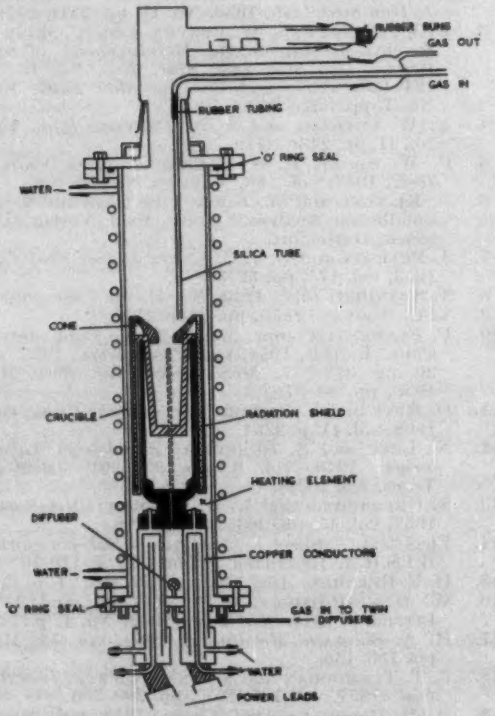

Fig. 1—Furnace unit

In theory, the reduction of the carbon monoxide partial pressure over the molten steel sample can be accomplished by the use of a streaming carrier gas as an alternative to a vacuum. The presence of the carrier-gas molecules might slightly decrease the rate of CO evolution but would not prevent the quantitative conversion of the oxygen to CO. The use of a carrier gas would have many advantages; thus, the apparatus could be operated at atmospheric pressure, thereby avoiding the use of expensive vacuum pumps, permitting the use of rubber connections and reducing the importance of slight leaks.

Preliminary experiments were made at the Central Research Laboratories of Richard Thomas and Baldwins Ltd. in which a carrier gas replaced the vacuum in the vacuum-fusion apparatus. The CO evolved was oxidized to CO_2 and absorbed in soda asbestos. A temperature of 1750° C was used in the melting chamber to obtain the rapid reduction of any alumina in the sample. Singer,* who used a tin bath operating at 1250° C, found that the reduction of alumina was very slow, necessitating a considerable reaction time. The results obtained confirmed the general validity of the carrier-gas technique as a

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* L. Singer, *Ind. Eng. Chem., Anal. Ed.*, 1940, vol. 12, pp. 127–130.

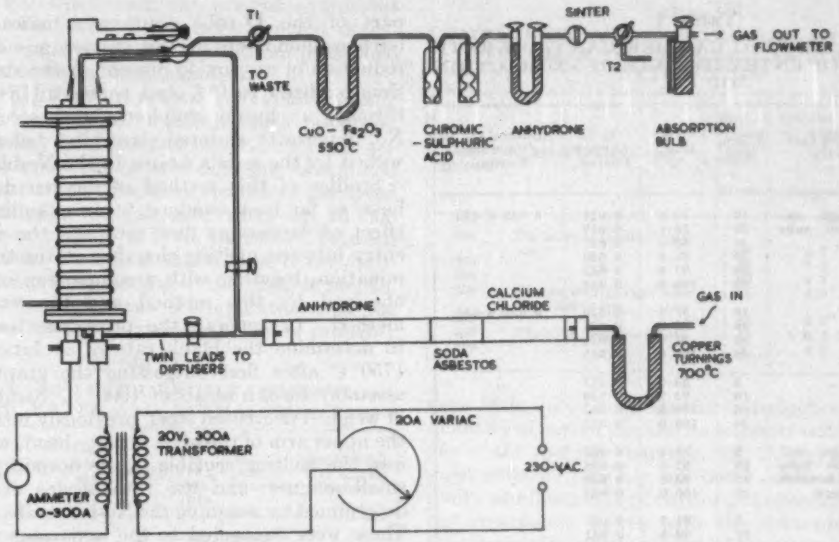

Fig. 2—Schematic diagram of equipment for oxygen determinations

basis for a rapid method for the determination of the oxygen content of steel irrespective of the alumina content. The present paper describes further work on the method performed on a completely new apparatus specially built for the investigation.

EXPERIMENTAL PROCEDURE

The apparatus used is shown diagrammatically in Figs. 1 and 2 and a photograph is given in Fig. 3. Cylinder argon is fed through a purification train consisting of copper turnings at 700° C followed by calcium chloride and soda asbestos; after final drying over anhydrone the gas is admitted to the furnace, which is similar to that reported by Cook and Speight.† Figure 1 shows the graphite heating element, radiation shield, and melting crucible, the two last-named being supported on the graphite element, which

† R. M. Cook and G. E. Speight, *J. Iron Steel Inst.*, 1954, vol. 176, pp. 252–256.

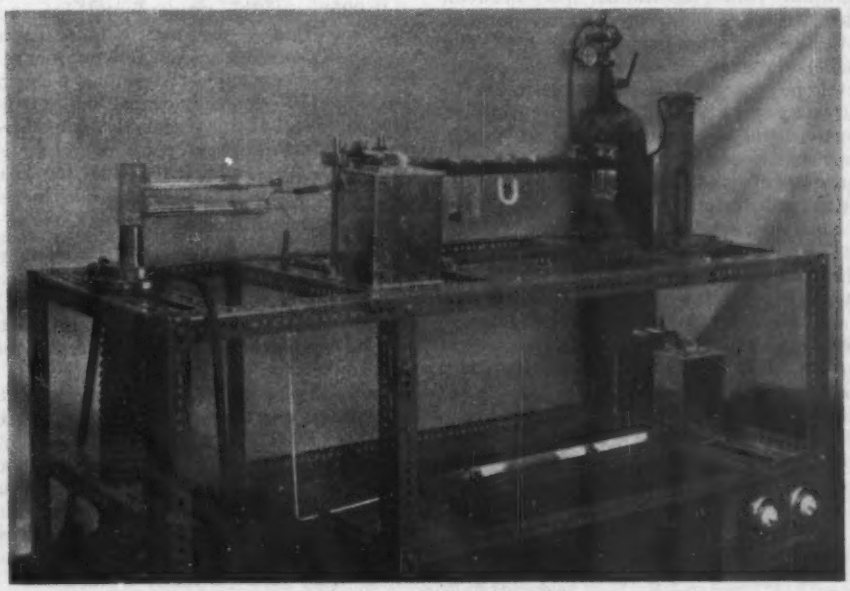

Fig. 3—Carrier-gas fusion apparatus

Table I

EFFECT OF VARYING CARRIER GAS FLOW RATE AND MODE OF ENTRY ON RATE OF EXTRACTION OF CO_2

Argon Flow Rate, ml/min	Type of Gas Entry	Time, min	Extraction, %	O_2, % (Argon Fusion)	Nominal O_2, % (Vacuum Fusion)
100	Through extension tube only	10	32·8	0·011	0·033–0·034
		20	56·6	0·019	
		30	80·6	0·027	
		40	87·5	0·030	
		50	97·0	0·032	
		60	100·0	0·033$_5$	
200	"	10	57·0	0·020	0·032–0·035
		20	80·0	0·028	
		30	97·5	0·034	
		40	100·0	0·035	
300	"	5	53·0	0·017	"
		10	93·7	0·030	
		15	100·0	0·032	
		20	100·0	0·032	
200	Through extension tube and bottom diffusers	5	71·8	0·023	"
		10	87·5	0·028	
		15	93·8	0·030	
		20	100·0	0·032	
300	"	5	81·9	0·027	"
		10	98·5	0·032	
		15	100·0	0·033	
		20	100·0	0·033	
300	Through bottom diffusers only	5	72·6	0·024	0·033–0·034
		10	97·0	0·032	
		15	100·0	0·033	
		20	100·0	0·033	

is in turn mounted upon the metal base flange by two water-cooled conductors. These are chromium-plated to reduce gas adsorption and are insulated from the base flange by airtight wax seals. The resistive current path between the two electrodes is created by sawing a longitudinal slit from the bottom of the resistor element to a point $\frac{1}{2}$ in. from the top.

A radiation shield consisting of two concentric thin-walled graphite tubes, the annular space between which is filled with — 200 mesh graphite powder, rests upon the end of the heating element. The melting crucible, designed to accommodate approx. 120 g of metal, is suspended inside the element to leave an annular gap of $\frac{1}{32}$ in., thus preventing an electrical short-circuit. The mouth of the crucible is fitted with a graphite cone which effectively prevents splashing and does not require the graphite stopper often used in vacuum-fusion equipment.

The furnace body is made from stainless-steel tubing 17 in. long × 3 in. i.d., water-cooled by a copper coil soldered to the outside. Power is supplied from the 230-V a.c. main via a 20-A max. Variac which feeds the primary of a 20-V 300-A step-down transformer, the secondary of which is connected to the water-cooled conductors. A 300-A max. ammeter is included in the secondary circuit.

Some of the purified argon is admitted to the furnace by means of a tube inserted into the glass furnace head and joined to a piece of silica tubing ending about $1\frac{1}{2}$ in. above the mouth of the graphite crucible, whilst a further gas stream is bled into the furnace body at the base via two simple diffusers. The gas leaves the furnace at a point adjacent to the inlet on the glass head and passes via a three-way tap *T*.1 (*see* Fig. 2) over copper-oxide–ferric-oxide reagent contained in a silica **U**-tube held at 550° C; the fore part of the **U**-tube contains a silica-wool filter. Carbon monoxide in the carrier gas arising from reduction of any oxide present in the steel sample is thus oxidized to CO_2 and passes in the gas stream through a chromic–sulphuric acid scrubber and a No. 3 porosity sintered-glass filter before being absorbed by the soda asbestos in the Nesbitt bulb.

Studies of this method of oxygen determination have so far been confined to an examination of the effect of carrier-gas flow rate and the mode of gas entry into the melting chamber on the time of determination, together with a comparison of the results obtained by this method and the vacuum-fusion method. In general, the procedure has been first to determine the blank rate of evolution of CO at 1750° C after first outgassing the graphite furnace assembly for 2 h at about 1900° C. Samples (5–10 g) of weighed degreased steel, previously introduced into the upper arm of the glass furnace head, were dropped into the melting crucible in the normal way using a small magnet, and the rate of gas evolution was determined by weighing the Nesbitt bulbs at intervals. These were connected to the apparatus via a three-way tap, *T*.2, so that it was possible to ascertain the weight of gas collected at different time intervals and at the same time maintain continuous gas absorption.

The results obtained using various flow rates and methods of gas introduction are given in Tables I and II. All the samples used contained appreciable amounts of alumina and in some cases were fully killed with aluminium.

DISCUSSION OF RESULTS

Accuracy of Results

With one exception (the value of 0·080% oxygen obtained at a flow rate of 200 ml/min on a nominal 0·068–0·070% sample), all the final results lie within ± 0·005% of the range found by vacuum-fusion analysis. In two instances a more precise analysis is possible, since an appreciable number of determinations have been made on samples containing 0·032–0·035% (16 determinations) and 0·033–0·034% oxygen (14). It may thus be calculated that the respective mean oxygen content and standard deviations are 0·034% and S.D. 0·0019% for the first sample, and 0·033% and S.D. 0·0014% for the second.

Time per Determination

The rapidity of the method varies markedly with the carrier-gas flow rate and is to some extent dependent upon the mode of introduction of the gas. However, at a flow rate of 300 ml/min a determination may be completed within 15 min as may be seen from the results quoted in Tables I and II.

Since the rapidity of an oxygen determination depends on the time required to purge the furnace chamber of CO it is of interest to consider briefly the factors which will reduce purging time to a minimum. Obviously the first consideration is to reduce the dead space as far as possible and at the same time to increase the carrier-gas flow rate compatible with expense and cooling of the resistor element. However, unless every effort is made to distribute the carrier gas to all parts of the melting chamber, CO may remain entrapped in pockets formed by the radiation

shields etc. For this reason the present equipment has been provided with a gas inlet directed downwards into the crucible and with diffusers positioned at the bottom of the melting chamber.

Tables I and II show the rates of gas evolution using different combinations of carrier-gas flow rates and positions of entry into the melting chamber. It appears that the use of the bottom diffusers, as opposed to using the extension tube alone, increases the speed of a determination at gas flow rates up to 300 ml/min. However, there is little difference between using the diffusers alone or a combination of the diffusers and the silica tube leading to the crucible mouth.

Because of the high furnace temperature and the multiple inlets for the carrier gas there is probably very little delay between the introduction of a small quantity of carrier gas and its intimate mixing with the gas of the melting chamber. On this hypothesis, the most efficient purging will occur when an infinitesimally small amount of carrier gas entering the chamber completely mixes with the contents before an infinitesimally small amount of the furnace gas leaves the chamber. Such a system can be treated mathematically (*see* Appendix). Thus, assuming initially (i.e. before the passage of any carrier gas) that the dead space contains all the CO,

$$\log r = 2 - \frac{X}{2 \cdot 303V} \qquad \text{.....(1)}$$

where V is the dead space, and r the residual percentage of CO (assuming 100% initially) in the dead space after the passage of volume X of carrier gas.

Because of other errors in the determination of oxygen, approximately 1% or less of the original CO may be allowed to remain in the dead space after purging. Equation (1) thus gives

$$X = 4 \cdot 606V \qquad \text{.....(2)}$$

It is thus possible from an estimate of the dead space V to calculate the total volume of carrier gas required. Table III shows a comparison of the calculated carrier-gas volumes required to give 99% extraction (equation (2)) compared with those found experimentally. The dead-space volumes were calculated from the furnace dimensions and it was assumed that, when using the diffusers, CO was contained only within the space above the graphite furnace assembly.

In view of the simplifying assumptions made in deriving equation (1), the agreement between the calculated and experimental carrier-gas volumes in Table III is satisfactory. Each calculated value is higher than its experimentally determined partner, suggesting possibly that the CO may flow out of the chamber by convection or that the effective dead spaces are smaller than those computed.

Sample Introduction

Carrier-gas methods normally used in the steel industry are invariably operated using intermittent sample introduction; to accomplish this on the present equipment a smaller-bore glass tube, sealed with a rubber bung, was fitted to the B.24 cap on the sample arm of the glass head. When tap $T.1$ is turned off and the rubber bung removed from the tube, the gas

Table II

COMPARISON OF CARRIER-GAS CONDITIONS WITH BLANK RATES AND EXTRACTION TIMES

Argon Flow Rate, ml/min	Type of Gas Entry	Blank Rate, mg/10 min	Batch	Time to 100% Extn., min	O_2, % (Argon Fusion)	Nominal O_2, % (Vacuum Fusion)
200	Through exit tube only	0·6	H	40	0·010	
,,	,,	0·6	H	40	0·009	0·010–0·013
,,	,,	1·5	M	40	0·008	
,,	,,	1·6	A	40	0·032	
,,	,,	1·4	B	40	0·032	
,,	,,	1·3	C	40	0·039	0·032–0·035
,,	,,	0·5	G	40	0·035	
,,	,,	0·6	H	40	0·031	
,,	,,	1·4	L	40	0·033	
,,	,,	1·3	C	40	0·045	
,,	,,	1·5	D	40	0·045	
,,	,,	1·5	D	40	0·044	0·043–0·049
,,	,,	1·4	L	40	0·049	
,,	,,	1·0	I	40	0·046	
,,	,,	1·4	L	40	0·045	
,,	,,	1·5	D	40	0·049	
,,	,,	1·5	D	40	0·058	0·052–0·055
,,	,,	1·5	D	40	0·055	
,,	,,	0·7	F	40	0·064	
,,	,,	1·3	E	40	0·058	0·062–0·069
,,	,,	1·3	E	40	0·065	
,,	,,	0·6	J	40	0·059	
,,	,,	1·1	K	40	0·068	
,,	,,	0·6	J	40	0·069	0·068–0·070
,,	,,	0·6	J	40	0·066	
,,	Through extension tube and bottom diffusers	1·1	N	20	0·033	
,,		1·1	N	20	0·037	0·032–0·035
,,		1·1	N	20	0·039	
,,		1·2	O	20	0·035	
,,	,,	1·2	O	20	0·032	
,,	,,	1·2	O	20	0·033	
,,	,,	1·2	P	30	0·067	0·068–0·070
,,	,,	1·2	P	25	0·080	
,,	,,	1·2	P	25	0·010	0·010–0·013
,,	,,	1·2	P	20	0·010	
300	Through extension tube only	1·1	Q	15	0·032	0·032–0·035
,,		1·0	Q	15	0·035	
,,	Through extension tube and bottom diffusers	1·1	Q	15	0·030	0·032–0·035
,,		0·8	Q	15	0·033	
,,		1·0	R	20	0·036	
,,		1·0	R	15	0·034	0·033–0·034
,,	,,	1·0	R	15	0·031	
,,	,,	1·0	R	15	0·032	
,,	,,	1·0	R	15	0·008	0·010–0·013
,,	,,	1·0	R	15	0·011	
,,	,,	1·0	R	15	0·071	0·067–0·070
200	Through bottom diffusers only	1·1	T	25	0·033	
,,		1·1	T	15	0·035	
,,		1·1	T	15	0·033	
300	,,	1·1	T	15	0·034	
,,	,,	1·1	T	15	0·033	0·033–0·034
,,	,,	1·1	T	15	0·033	
,,	Through extension tube and bottom diffusers	1·0	S	15	0·031*	0·033–0·034
,,		1·0	S	15	0·031*	
,,		1·0	S	15	0·036*	
,,		1·0	S	15	0·034*	

* Samples introduced intermittently

Table III

COMPARISON OF OBSERVED AND CALCULATED VOLUMES OF CARRIER-GAS FOR 99% EXTRACTION

Gas Flow Rate, ml/min	Mode of Gas Entry	Estimated Dead Space V, litres	Carrier Gas Volume to Achieve 99% Extraction, litres	
			Observed	Calculated
100	Through extension tube only	1·80	5·7	8·3
200	,,	1·80	7·2	8·3
300	,,	1·80	4·5	8·3
200	Through extension tube and diffusers	1·15	4·0	5·3
300		1·15	4·2	5·3
200	Through diffusers only	1·15	5·0, 3·0	5·3
300	,,	1·15	4·2	5·3

flow at 300 ml/min is fast enough to prevent ingress of air to the equipment. Steel samples may then be introduced, the bung replaced, and the gas stream diverted into the absorption train. The blank rate of CO evolution was determined before and after introduction of a sample into the glass head in this way and was found to be unchanged. Several analyses using this means of loading the sample into the head were carried out and the results, which are noted in Table II, are in close agreement with the nominal value.

Blank Rate

The blank rates are high compared with those obtained with vacuum-fusion equipment; thus, on a sample weight of 10 g of steel containing 0·05% oxygen, the blank would amount to about 10% of the total CO_2 weighed when using a carrier-gas flow rate of 200 ml/min. A 20% variation in the blank would therefore give rise to an analytical error of ± 0·001% oxygen on the above sample weight.

All blank rates are given in Table II, and those with the same batch letter were determined on the same day. It is interesting to note that, with the exception of batch *Q*, the blank rates in any one day are constant; marked differences exist from day to day at the 200 ml/min flow rate.

In all the work so far described, argon has been used as the carrier gas. Whilst this gas is ideal chemically, experiments have been made using white-spot nitrogen, which is cheaper and more generally available. The analytical results obtained were as accurate as those involving argon, and nitrogen is therefore recommended as the more suitable for routine analysis.

A systematic examination has been made of the factors contributing to the blank rate when using white-spot nitrogen. It has definitely been established that the major source of blank gas is the graphite furnace assembly. Thus by keeping the furnace temperature greater than about 700° C continuously for several days and increasing to about 1750° C for blank rate determinations, values of about 0·2 mg CO_2 per 10 min have been obtained. No reduction of blank rate has resulted from increased carrier-gas purification by copper furnaces etc.

Further Work

Although the blank rates are sufficiently low and constant in any one day for routine analytical purposes, efforts are being made to reduce them to negligible proportions. Particular attention is being given to forms of outgassing procedure suitable for equipment in daily operation.

There are a number of other points of interest which will repay further study. For example, more sensitive techniques may be used for determining the carbon dioxide evolved (e.g. volumetric and conductivity methods). Provided these are simple and inexpensive enough to be operated in a routine laboratory, they would enable a smaller sample weight to be used, thus reducing the frequency of crucible replacement.

CONCLUSIONS

(1) It has been shown that the determination of oxygen in steel by fusion of the metal in a carbon crucible in a stream of an inert carrier gas may be effected within 15 min with a standard deviation of about 0·0016% oxygen.

(2) The method is operated at atmospheric pressure, resulting in a considerable saving on the normal cost of a vacuum-fusion equipment. In addition, the method does not require operators skilled in vacuum technique, the basic technique being much the same as that used on combustion carbon or sulphur determinations.

(3) Samples may be introduced into the equipment as desired.

(4) The blank rate is high but is reasonably constant and does not therefore give rise to any appreciable error. The graphite furnace assembly has been shown to be the major source of ' blank ' gas and further work is being carried out in an attempt to arrive at the optimum outgassing conditions.

Acknowledgments

The authors wish to express their gratitude to Mr. S. Hall for undertaking many painstaking experiments and to Mr. R. A. Hacking, Director of Research, Richard Thomas and Baldwins Ltd., for permission to publish this paper.

APPENDIX

Derivation of Purging Rate Equation

Consider a dead space volume V cm³ containing 100% of gas A (carbon monoxide). Introduce v cm³ of carrier gas B and allow to mix completely. The diluted gas now contains:

$$100\,\frac{V}{V+v}\,\%\,A$$

Allow v cm³ of the mixture to leave the chamber, thus reducing the pressure to the original value.

If the procedure is repeated, the dead space will contain

$$100\left\{\frac{V}{V+v}\times\frac{V}{V+v}\right\}=100\,\frac{V^2}{(V+v)^2}\,\%\,A$$

After n such operations, the percentage r of component A in the dead space is given by

$$r=100\,\frac{V^n}{(V+v)^n}$$

Assume now that a given purging treatment requires a total volume X cm³ of carrier gas. If this quantity is divided into n batches each of v cm³ which are in turn introduced into the chamber, equilibriated, and v cm³ of mixture extracted, the final percentage of component A in the chamber is given by:

$$r=100\,\frac{V^n}{\left(V+\frac{X}{n}\right)^n}=\frac{100}{\left(1+\frac{X}{nV}\right)^n}$$

Thus for a given X/V ratio, r decreases as n increases, and ideally the most efficient purging will be obtained when $n\to\infty$ and $v\to 0$. Under these conditions if $X/V=A$,

$$r=\frac{100}{\left(1+\frac{X}{nV}\right)^n}=100\left(1+\frac{A}{n}\right)^{-n}$$

$$=100\left(1-A+\frac{A^2}{2!}-\frac{A^3}{3!}+\ldots\ldots\right)$$

$$=100e^{-A}$$

or, taking logarithms of both sides and substituting for A,

$$\log r=2-\frac{X}{2{\cdot}303V}.$$

A Thermodynamic Study of Fe–Ca–P–O, Fe–Ca–Si–P–O, and Some Complex Molten Silicophosphate Systems

By E. T. Turkdogan and Patricia M. Bills

SYNOPSIS

The ferric-ferrous iron reaction was studied by equilibrating pure Fe–Ca–P–O and Fe–Ca–Si–P–O molten systems with carbon-dioxide–carbon-monoxide mixtures of known compositions at 1550° C. In the iron–calcium phosphate system there is a large miscibility gap at $p_{CO_2}/p_{CO} = 11 \cdot 4$, but at higher oxygen potentials the composition range of this miscibility gap decreases. Comparison of these results on the Fe–Ca–P–O system with the available data on the Fe–Ca–Si–O system reveals interesting facts on some of their physico-chemical properties. An important outcome of this work is the discovery of a simple relationship between the atomic concentration of trivalent iron and the atomic concentrations of silicon and phosphorus. At low oxygen potentials, for a given p_{CO_2}/p_{CO} ratio, the atomic concentration of trivalent iron varies solely with the sum of the atom fractions $4N_{Si} + 5N_P$, irrespective of the relative proportions of silicon and phosphorus. It is also shown that, under certain conditions, divalent cations Ca^{2+}, Mg^{2+}, Mn^{2+}, and Fe^{2+} are equivalent in their effects on the trivalent iron concentration. A method has been suggested whereby the oxygen potentials of a wide range of basic steelmaking slags can be estimated with a fair degree of accuracy for any temperature between 1500° and 1700° C.

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Introduction

IN A PREVIOUS PAPER the authors[1] presented their experimental data on the oxygen partial pressures of pure iron silicates, phosphates, and silicophosphates. One of the interesting facts revealed by the previous work was that phosphorus pentoxide lowered the Fe^{3+}/Fe^{2+} ratio to a greater extent than did silica, at the same concentration and oxygen potential. In other words, molecular concentrations of the acidic oxides, silica and phosphorus pentoxide, could not be regarded as equivalent.

In the present paper the results are submitted on some thermodynamic studies of molten calcium phosphates and calcium silicophosphates containing iron oxides.

EXPERIMENTAL

The apparatus and the experimental procedure were the same as those described previously.[1] That is, about 2 g of a mixture of ferrous oxide, ferric oxide, and calcium phosphate, with or without calcium silicate, was placed in a platinum thimble ($\frac{1}{2}$ in. dia. $\times$ $\frac{1}{2}$ in. long) which was then suspended by a platinum wire in a vertical recrystallized alumina tube at 1550° C in a stream of carbon-dioxide–carbon-monoxide mixture of known composition. At the end of the experiment the slag was quenched rapidly and analysed for its constituent oxides.

Fig. 1—Photomicrograph showing immiscibility in the Fe–Ca–P–O system

In addition to the materials described previously, four batches of calcium phosphates were initially prepared by heating, in air at 1000° C, mixtures of Analar di-ammonium hydrogen phosphate and Analar calcium carbonate, in the desired proportions. The molar CaO/P_2O_5 ratios in these phosphates were 2, 4, 9, and 30. In experiments with silicophosphates, the master calcium phosphates were mixed with the required proportions of calcined calcium oxide of reagent grade and fine silica prepared from purified natural quartz.

In experiments with iron–calcium phosphates, the slags were analysed after each experiment for divalent and trivalent iron and phosphorus; calcium oxide was estimated by difference. With iron–calcium silicophosphates, however, calcium oxide was also determined by analysis and only silica was estimated by difference. A few samples when analysed completely gave a total of $100 \pm 0 \cdot 5\%$.

For further details on experimental techniques

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Dr. Turkdogan is Head of, and Mrs. Bills is a member of, the Physical Chemistry Section of the Chemistry Department of B.I.S.R.A.

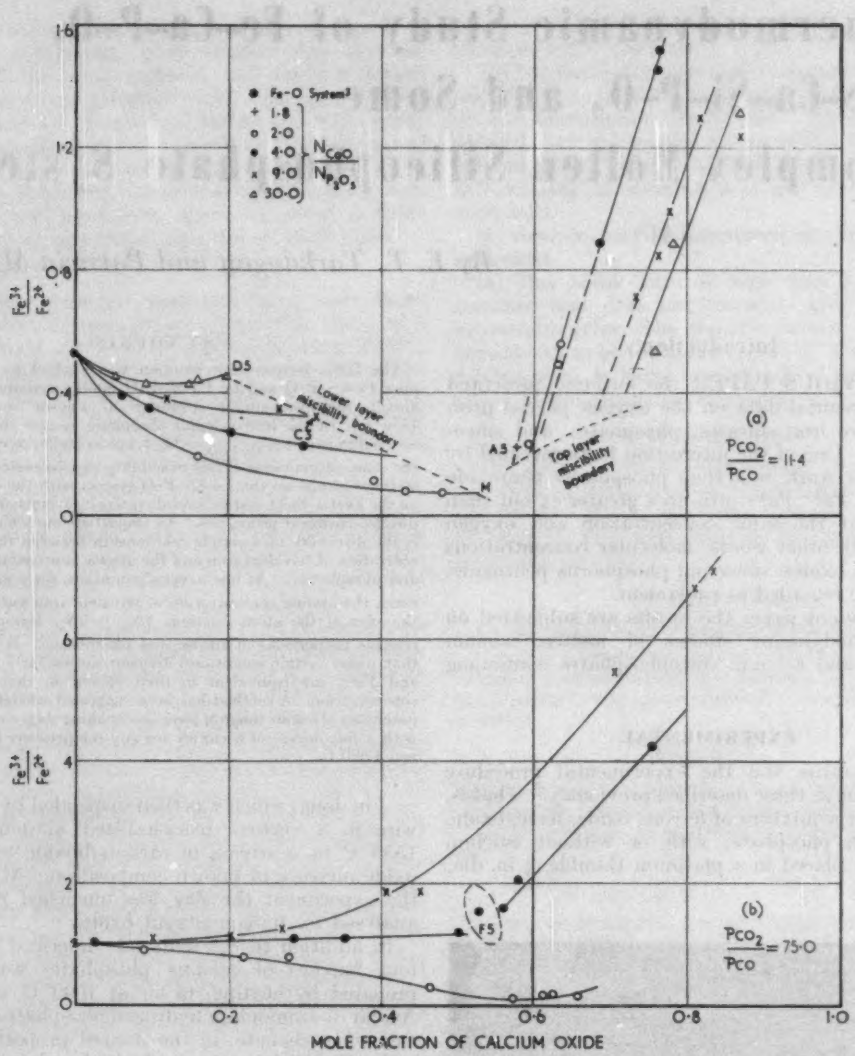


Fig. 2—Variation of Fe^{3+}/Fe^{2+} with composition in Fe–Ca–P–O system at 1550° C

reference should be made to the authors' previous paper.

RESULTS

Fe–Ca–P–O System

All the experiments were carried out on this system at 1550° C with gas ratios $p_{CO_2}/p_{CO} = 11{\cdot}4$ and $75{\cdot}0$. The experimental results are given in Tables I and II for these gas ratios. For convenience the slag composition is given in terms of weight percentages of oxides, mole fractions of oxides, and atom fractions of the constituent elements, together with a few calculated ratios.

One of the important properties of the molten Fe–Ca–P–O system is that, within certain ranges of composition and oxygen potential, the system separates into two liquids. The miscibility gap in this system was determined accurately by Oelsen and Maetz,[2] who melted mixtures of iron phosphate and calcium phosphate in iron crucibles at 1400° C in nitrogen. After cooling the crucible with its contents, analysis was made of the two phases.

A few preliminary experiments were carried out at 1550° C and with a gas mixture having $p_{CO_2}/p_{CO} = 11{\cdot}4$ to reveal the extent of the miscibility gap under the stated conditions. Visual examination of the solidified sample revealed quite readily whether or not the molten phosphate separated into two liquids. Some of the samples were mounted in bakelite and polished for microscopic examination under reflected light. Figure 1 is a photomicrograph of the vertical section of a phosphate sample exhibiting two phases. The lower layer rich in iron oxides took a better polish than the phosphate-rich top layer, hence the bottom layer appears brighter under reflected light. Although the two phases appear to be well separated, closer

Table I

EXPERIMENTAL RESULTS ON Fe–Ca–P–O SYSTEM AT 1550° C AND $P_{CO_2}/P_{CO} = 11{\cdot}4$

(a) Bottom layer (b) Top layer

No.	Wt-%				Mole Fraction				Atom Fraction					$\frac{Fe^{2+}}{Fe^{3+}}$	$\frac{N_{CaO}}{N_{P_2O_5}}$
	CaO*	FeO	Fe_2O_3	P_2O_5	CaO	FeO	Fe_2O_3	P_2O_5	Ca^{2+}	Fe^{2+}	Fe^{3+}	P^{5+}	O^{2-}		
(a)															
A 1	11·12	61·84	13·14	13·90	0·160	0·695	0·066	0·079	0·0617	0·2677	0·0512	0·0608	0·5586	0·191	2·02
2	26·80	35·53	4·58	33·09	0·388	0·401	0·023	0·188	0·1290	0·1333	0·0153	0·1250	0·5977	0·116	2·06
3	29·63	31·35	2·59	36·43	0·427	0·352	0·013	0·208	0·1387	0·1144	0·0084	0·1350	0·6035	0·074	2·05
4	32·75	23·47	1·84	41·96	0·480	0·268	0·009	0·243	0·1460	0·0818	0·0058	0·1478	0·6186	0·071	1·97
B 1	4·11	65·05	28·20	2·64	0·063	0·771	0·150	0·016	0·0249	0·3048	0·1186	0·0126	0·5391	0·390	3·94
2	6·63	64·33	24·90	4·14	0·099	0·747	0·130	0·024	0·0394	0·2976	0·1036	0·0191	0·5401	0·348	4·12
3	14·19	59·29	17·62	8·90	0·202	0·659	0·089	0·050	0·0803	0·2619	0·0707	0·0397	0·5475	0·267	4·04
4	21·32	52·09	12·92	13·67	0·297	0·565	0·063	0·075	0·1159	0·2204	0·0492	0·0584	0·5561	0·223	3·96
C 1	8·10	62·97	26·67	2·26	0·120	0·728	0·139	0·013	0·0483	0·2934	0·1118	0·0106	0·5359	0·381	9·23
2	18·89	54·78	21·07	5·26	0·266	0·601	0·104	0·029	0·1083	0·2446	0·0847	0·0236	0·5388	0·346	9·17
3	22·84	52·40	18·29	6·47	0·314	0·563	0·088	0·035	0·1288	0·2309	0·0722	0·0286	0·5395	0·314	8·97
D 1	3·40	64·25	32·07	0·28	0·052	0·773	0·173	0·0017	0·0207	0·3055	0·1372	0·0013	0·5353	0·449	30·59
2	6·04	63·11	30·33	0·52	0·091	0·745	0·161	0·0031	0·0365	0·2980	0·1289	0·0025	0·5341	0·432	29·35
3	9·98	60·44	28·75	0·83	0·148	0·698	0·149	0·0048	0·0599	0·2824	0·1206	0·0039	0·5330	0·428	30·83
4	10·67	59·65	28·79	0·89	0·158	0·688	0·149	0·0052	0·0637	0·2781	0·1207	0·0042	0·5333	0·434	30·38
5	13·46	56·95	28·51	1·08	0·197	0·650	0·146	0·0062	0·0797	0·2633	0·1186	0·0050	0·5334	0·450	31·77
(b)															
A 5	37·35	7·82	1·93	52·90	0·578	0·094	0·010	0·321	0·1579	0·0258	0·0057	0·1767	0·6339	0·222	1·79
6	39·51	8·87	2·24	49·38	0·592	0·104	0·012	0·292	0·1693	0·0298	0·0070	0·1670	0·6269	0·227	2·03
7	41·55	4·25	2·30	51·90	0·629	0·050	0·012	0·309	0·1756	0·0140	0·0067	0·1726	0·6311	0·487	2·03
8	41·77	3·96	2·45	51·82	0·631	0·047	0·013	0·309	0·1760	0·0131	0·0073	0·1725	0·6311	0·554	2·04
B 5	49·84	9·17	9·05	31·94	0·685	0·098	0·044	0·173	0·2286	0·0328	0·0293	0·1154	0·5939	0·888	3·96
6	56·66	3·02	4·91	35·41	0·759	0·031	0·023	0·187	0·2523	0·0105	0·0154	0·1246	0·5972	1·459	4·06
7	56·98	2·76	4·64	35·62	0·762	0·028	0·022	0·188	0·2535	0·0093	0·0146	0·1251	0·5975	1·518	4·05
C 4	58·38	14·06	11·19	16·35	0·732	0·138	0·049	0·081	0·2868	0·0541	0·0384	0·0635	0·5572	0·718	9·04
5	60·89	11·29	10·62	17·20	0·759	0·110	0·046	0·085	0·2962	0·0429	0·0359	0·0663	0·5587	0·846	8·93
6	62·36	9·50	10·47	17·67	0·776	0·092	0·046	0·086	0·3022	0·0358	0·0358	0·0670	0·5592	0·992	9·02
7	66·83	5·91	8·55	18·71	0·817	0·056	0·037	0·090	0·3188	0·0220	0·0287	0·0705	0·5600	1·303	9·08
8	73·63	2·40	3·29	20·68	0·868	0·022	0·014	0·096	0·3441	0·0088	0·0108	0·0763	0·5600	1·230	9·04
D 6	62·02	20·44	12·33	5·21	0·736	0·189	0·051	0·024	0·3230	0·0831	0·0451	0·0214	0·5274	0·542	30·66
7	67·83	13·31	13·22	5·64	0·797	0·122	0·055	0·026	0·3475	0·0532	0·0475	0·0228	0·5290	0·893	30·65
8	75·77	7·17	10·44	6·62	0·865	0·064	0·041	0·030	0·3801	0·0281	0·0368	0·0262	0·5288	1·310	28·83

* By difference

examination of Fig. 1 shows that the bottom layer contains a number of grey spherical particles which appear identical to the top layer. The presence of these microscopic inclusions may be due to:

(i) Incomplete separation of the two liquids
(ii) Slight mixing of top layer with bottom layer during dropping of the sample, or
(iii) The fact that further separation in the liquid phase takes place during cooling of the sample.

Table II

EXPERIMENTAL RESULTS ON Fe–Ca–P–O SYSTEM AT 1550° C AND $P_{CO_2}/P_{CO} = 75{\cdot}0$

No.	Wt-%				Mole Fraction				Atom Fraction					$\frac{Fe^{2+}}{Fe^{3+}}$	$\frac{N_{CaO}}{N_{P_2O_5}}$
	CaO*	FeO	Fe_2O_3	P_2O_5	CaO	FeO	Fe_2O_3	P_2O_5	Ca^{2+}	Fe^{2+}	Fe^{3+}	P^{5+}	O^{2-}		
E 1	5·24	44·22	43·99	6·55	0·0907	0·5970	0·2675	0·0448	0·0300	0·1976	0·1769	0·0293	0·5662	0·895	2·02
2	13·31	37·44	32·80	16·45	0·2198	0·4826	0·1903	0·1073	0·0708	0·1554	0·1224	0·0690	0·5824	0·788	2·06
3	17·11	32·89	28·58	21·42	0·2792	0·4189	0·1639	0·1380	0·0880	0·1318	0·1030	0·0865	0·5907	0·781	2·02
4	31·92	23·10	6·31	38·67	0·4634	0·2618	0·0322	0·2216	0·1468	0·0828	0·0203	0·1400	0·6101	0·246	2·09
5	38·81	11·89	1·30	48·00	0·5748	0·1376	0·0067	0·2809	0·1683	0·0402	0·0039	0·1638	0·6238	0·098	2·04
6	40·99	7·41	1·10	50·50	0·6109	0·0860	0·0058	0·2973	0·1745	0·0246	0·0033	0·1692	0·6283	0·134	2·06
7	41·75	5·05	0·92	52·28	0·6263	0·0591	0·0048	0·3098	0·1757	0·0167	0·0027	0·1738	0·6311	0·164	2·02
8	43·96	1·66	0·28	54·10	0·6587	0·0194	0·0015	0·3204	0·1831	0·0054	0·0008	0·1774	0·6333	0·152	2·06
F 1	1·43	46·20	51·47	0·90	0·0255	0·6475	0·3246	0·0064	0·0085	0·2149	0·2153	0·0042	0·5571	1·00	4·00
2	17·21	32·86	39·11	10·82	0·2826	0·4215	0·2257	0·0702	0·0935	0·1392	0·1490	0·0463	0·5720	1·07	4·02
3	22·01	29·04	35·12	13·83	0·3522	0·3628	0·1975	0·0875	0·1164	0·1198	0·1303	0·0577	0·5758	1·09	4·03
4	33·44	19·74	25·67	21·15	0·5049	0·2326	0·1363	0·1262	0·1663	0·0766	0·0895	0·0830	0·5846	1·17	4·00
5	34·70	16·19	27·11	22·00	0·5292	0·1932	0·1460	0·1326	0·1710	0·0622	0·0937	0·0855	0·5876	1·51	3·99
6	37·23	14·39	25·12	23·26	0·5599	0·1689	0·1330	0·1382	0·1815	0·0547	0·0859	0·0894	0·5885	1·57	4·05
7	38·17	11·39	25·78	24·66	0·5796	0·1350	0·1375	0·1479	0·1843	0·0428	0·0873	0·0936	0·5920	2·04	3·92
8	55·68	1·81	8·45	34·06	0·7574	0·0192	0·0404	0·1830	0·2500	0·0063	0·0266	0·1203	0·5968	4·20	4·08
G 1	5·88	41·94	50·52	1·66	0·1032	0·5739	0·3114	0·0115	0·0345	0·1923	0·2083	0·0073	0·5576	1·08	8·97
2	11·95	37·12	47·53	3·40	0·2027	0·4912	0·2633	0·0228	0·0685	0·1661	0·1913	0·0150	0·5591	1·15	8·90
3	16·42	33·21	45·82	4·55	0·2726	0·4303	0·2673	0·0298	0·0926	0·1461	0·1812	0·0199	0·5602	1·24	9·13
4	25·11	22·50	45·40	6·99	0·4091	0·2860	0·2598	0·0451	0·1364	0·0953	0·1728	0·0299	0·5657	1·82	9·05
5	28·54	20·72	42·64	8·10	0·4536	0·2573	0·2382	0·0509	0·1531	0·0866	0·1603	0·0342	0·5658	1·85	8·91
6	49·92	5·10	30·70	14·28	0·7062	0·0566	0·1534	0·0808	0·2486	0·0198	0·1072	0·0558	0·5686	5·41	8·85
7	63·50	2·21	16·77	17·52	0·8137	0·0221	0·0755	0·0887	0·3133	0·0085	0·0580	0·0679	0·5523	6·83	9·17
8	67·25	1·55	12·21	18·99	0·8379	0·0151	0·0535	0·0935	0·3195	0·0057	0·0407	0·0708	0·5633	7·09	8·96

* By difference

Table III

EXPERIMENTAL RESULTS ON Fe–Ca–Si–P–O SYSTEM AT 1550° C AND $p_{CO_2}/p_{CO} = 2{\cdot}5$

No.	Wt-%					Atom Fraction						Calculated Values	
	CaO	FeO	Fe_2O_3	SiO_2*	P_2O_5	Ca^{2+}	Fe^{3+}	Fe^{2+}	Si^{4+}	P^{5+}	O^{2-}	4Si + 5P	$\frac{Ca}{4Si + 5P}$
H 1	25·19	12·76	1·27	18·49	32·29	0·1324	0·0375	0·0034	0·0753	0·0960	0·6554	0·781	0·17
2	18·76	48·93	15·56	4·88	11·87	0·1024	0·2066	0·0597	0·0248	0·0512	0·5533	0·355	0·29
3	30·46	32·90	9·45	7·90	19·29	0·1491	0·1257	0·0325	0·0361	0·0745	0·5821	0·517	0·29
4	41·60	19·56	1·73	10·77	26·34	0·1893	0·0695	0·0055	0·0457	0·0947	0·5953	0·656	0·29
5	55·08	6·29	16·04	11·53	11·06	0·2610	0·0233	0·0534	0·0510	0·0414	0·5699	0·411	0·64
6	17·81	53·36	23·25	4·33	1·25	0·1016	0·2376	0·0931	0·0231	0·0056	0·5390	0·120	0·85
7	23·79	50·93	18·64	4·92	1·72	0·1334	0·2230	0·0734	0·0258	0·0076	0·5368	0·141	0·94
8	31·37	38·62	21·53	6·78	2·30	0·1693	0·1602	0·0816	0·0341	0·0098	0·5450	0·185	0·92
9	40·38	26·70	20·56	9·07	3·35	0·2092	0·1080	0·0745	0·0438	0·0137	0·5508	0·244	0·86

* By difference

The latter, however, is unlikely to have occurred as the samples were chilled very rapidly by dropping the crucible and its contents from the hot zone of the reaction chamber on to a water-cooled copper block at the bottom of the tube. Except in a few cases, the separation of the two layers, after solidification of the sample, was not completely satisfactory from the viewpoint of determining accurately the composition of the two layers.

After roughly determining the extent of immiscibility, a series of experiments was carried out with phosphates which were within the one phase field. The results shown in Table I fall into two groups: (*a*) bottom layer, which is rich in iron oxides, and (*b*) top layer, which is rich in calcium phosphate. In Fig. 2*a* the Fe^{3+}/Fe^{2+} ratio is plotted against the concentration of calcium oxide for ranges of CaO/P_2O_5 ratios. The value of $Fe^{3+}/Fe^{2+} = 0{\cdot}535$ on the ordinate for the pure Fe–O system is derived from the work of Darken and Gurry.[3] The position of the miscibility boundary for the lower layer is reasonably accurate and is based on the following evidence: in one of the melts containing two phases, the bottom and top layers were separated satisfactorily and therefore the composition of this sample *D* 5 should lie on the miscibility boundary. The chemical analysis of this sample gave molar $CaO/P_2O_5 = 31{\cdot}8$ which may be grouped with melts having molar $CaO/P_2O_5 = 30$. In melt *C* 3 there was a small quantity of the second phase which was removed completely from the bottom layer before the latter was sampled for analysis. To justify the position of the straight (dotted) line passing through these points, a third melt with an initial gross composition indicated by point *M* in Fig. 2*a* was equilibrated; there appeared to be a slight trace of the top layer. Owing to the difficulty of sampling, this sample was not analysed.

The melts whose compositions fall on the other side of the miscibility gap are given on the right-hand side in Fig. 2*a*. The composition limit of this phase was not determined and the boundary drawn by the dotted curve has been guessed. However, it should be noted that the sample *A* 5 (phosphate-rich layer) was separated from the melt which showed two layers, the iron-oxide-rich layer being the sample *D* 5 as mentioned above. In these two phases in equilibrium with one another, the CaO/P_2O_5 ratio in the bottom layer is much higher than that in the top layer.

Figure 2*b* shows the relationship between the Fe^{3+}/Fe^{2+} ratio and calcium oxide concentration for the gas ratio 75·0. Only in the case of experiment *F* 5 did the melt separate into two liquids. The miscibility gap in this system will, therefore, be confined to a region shown approximately by the dotted curve in Fig. 2*b*.

It should be pointed out that no loss of phosphorus was observed in these and subsequent experiments. This is illustrated by the molar CaO/P_2O_5 ratios given

Table IV

EXPERIMENTAL RESULTS ON Fe–Ca–Si–P–O SYSTEM AT 1550° C AND $p_{CO_2}/p_{CO} = 11{\cdot}4$

No.	Wt-%					Atom Fraction						Calculated Values	
	CaO	FeO	Fe_2O_3	SiO_2*	P_2O_5	Ca^{2+}	Fe^{3+}	Fe^{2+}	Si^{4+}	P^{5+}	O^{2-}	4Si + 5P	$\frac{Ca}{4Si + 5P}$
I 1	16·83	43·57	28·52	8·19	2·89	0·0922	0·1861	0·1096	0·0419	0·0125	0·5577	0·230	0·40
2	20·44	36·37	31·89	7·25	4·35	0·1102	0·1531	0·1197	0·0365	0·0185	0·5620	0·239	0·46
3	23·30	35·43	26·08	12·08	3·25	0·1225	0·1452	0·0961	0·0592	0·0135	0·5637	0·304	0·40
4	30·59	29·74	20·21	13·88	5·58	0·1550	0·1176	0·0719	0·0657	0·0223	0·5675	0·374	0·41
5	31·66	28·78	18·03	15·68	5·85	0·1584	0·1124	0·0634	0·0732	0·0230	0·5696	0·408	0·39
6	32·50	28·34	19·35	15·34	4·47	0·1637	0·1114	0·0685	0·0721	0·0178	0·5665	0·377	0·43
7	38·01	22·65	17·56	17·50	4·28	0·1872	0·0871	0·0607	0·0805	0·0166	0·5679	0·405	0·46
8	42·60	20·06	11·34	18·07	7·93	0·2039	0·0750	0·0381	0·0806	0·0299	0·5723	0·473	0·43
9	46·09	11·32	7·98	15·92	18·69	0·2094	0·0401	0·0255	0·0675	0·0671	0·5904	0·606	0·35
10	48·19	12·18	7·93	21·43	10·27	0·2213	0·0437	0·0256	0·0919	0·0372	0·5803	0·554	0·40
J 1	14·55	47·98	32·75	3·46	1·26	0·0833	0·2145	0·1317	0·0185	0·0056	0·5464	0·102	0·81
2	16·40	42·65	35·13	3·84	1·98	0·0925	0·1879	0·1392	0·0202	0·0087	0·5515	0·124	0·75
3	23·00	37·34	32·38	5·42	1·86	0·1267	0·1606	0·1253	0·0279	0·0081	0·5514	0·152	0·83
4	27·90	33·51	29·80	5·66	4·03	0·1455	0·1409	0·1128	0·0285	0·0171	0·5552	0·199	0·73
5	31·53	26·88	31·14	7·87	2·58	0·1669	0·1111	0·1158	0·0389	0·0108	0·5565	0·210	0·79
6	39·15	19·86	28·35	9·80	2·84	0·2014	0·0798	0·1024	0·0471	0·0115	0·5578	0·246	0·82
7	48·40	12·85	23·48	8·64	6·63	0·2414	0·0500	0·0821	0·0402	0·0261	0·5602	0·291	0·83

* By difference

Table V

EXPERIMENTAL RESULTS ON Fe–Ca–Si–P–O SYSTEM AT 1550° C AND $p_{CO_2}/p_{CO} = 75 \cdot 0$

No.	Wt-%					Atom Fraction						Calculated Values	
	CaO	FeO	Fe_2O_3	SiO_2*	P_2O_5	Ca^{2+}	Fe^{2+}	Fe^{3+}	Si^{4+}	P^{5+}	O^{2-}	4Si + 5P	$\frac{Ca}{4Si + 5P}$
K 1	5·47	45·58	37·24	8·24	3·47	0·0304	0·1975	0·1452	0·0427	0·0152	0·5690	0·247	0·12
2	29·77	22·70	11·46	10·95	25·12	0·1382	0·0822	0·0374	0·0474	0·0921	0·6027	0·650	0·21
3	42·15	12·34	7·23	11·58	26·70	0·1894	0·0433	0·0229	0·0486	0·0948	0·6010	0·668	0·28
L 1	15·51	35·37	40·39	4·91	3·82	0·0854	0·1521	0·1564	0·0252	0·0166	0·5643	0·184	0·46
2	20·54	29·19	38·35	4·86	7·06	0·1097	0·1218	0·1440	0·0242	0·0298	0·5705	0·246	0·44
3	33·21	20·93	16·98	7·87	21·02	0·1589	0·0781	0·0570	0·0351	0·0794	0·5915	0·537	0·30
4	44·50	11·01	7·28	9·05	28·16	0·2003	0·0387	0·0230	0·0380	0·1001	0·5999	0·623	0·32
M 1	48·97	7·64	24·77	8·78	9·84	0·2387	0·0291	0·0849	0·0399	0·0379	0·5695	0·249	0·68
2	53·43	3·31	25·02	8·38	9·86	0·2585	0·0125	0·0851	0·0378	0·0377	0·5684	0·340	0·76
N 1	37·09	13·03	37·18	5·81	6·89	0·1899	0·0521	0·1339	0·0279	0·0279	0·5683	0·251	0·88
2	50·49	3·19	29·82	6·42	10·09	0·2471	0·0122	0·1029	0·0293	0·0390	0·5695	0·312	0·79
3	56·82	4·33	19·82	15·02	4·01	0·2728	0·0162	0·0668	0·0673	0·0152	0·5617	0·345	0·79
4	62·29	1·66	17·57	3·75	14·73	0·2977	0·0062	0·0590	0·0167	0·0556	0·5648	0·345	0·86
5	63·48	1·84	15·46	4·16	15·06	0·3019	0·0068	0·0516	0·0185	0·0566	0·5646	0·357	0·85
O 1	30·95	27·39	36·23	2·56	2·87	0·1688	0·1166	0·1388	0·0131	0·0123	0·5504	0·114	1·48
2	37·23	15·09	41·27	3·30	3·11	0·1976	0·0625	0·1540	0·0164	0·0130	0·5565	0·131	1·51

* By difference

in the last columns of Tables I and II. These values are in close agreement with those in the original mixtures where, as pointed out before, CaO/P_2O_5 ratios were 2, 4, 9, and 30. However, had the experiments been carried out under more reducing conditions, there might have been some reduction of the phosphates.

The extrapolation of the curves to zero calcium phosphate again agrees well with the value $Fe^{3+}/Fe^{2+} = 1 \cdot 00$ derived from the results of Darken and Gurry.[3]

Fe–Ca–Si–P–O System

Four series of experiments were carried out on this system, all at 1550° C. In each series, the composition of the melt was varied and ferric–ferrous equilibrium was established at a given oxygen potential. The gas ratios employed were $p_{CO_2}/p_{CO} = 2 \cdot 5$, 11·4, and 75·0, and a few experiments were made in a stream of air. The experimental results are given in Tables III–VI, each for a fixed oxygen potential. The compositions of the melts are given in weight percentages and atom fractions. For the reasons given later, the mole fractions of oxides are not included in these tables. In these experiments the compositions of the melts studied varied over a wide range, as shown in Table VII. Because of the complexity of the system the results will be discussed later in the paper.

DISCUSSION

Iron–Calcium Silicates and Phosphates

Comparison of the results of Oelsen and Maetz[2] with the present work indicates clearly that the miscibility gap in the Fe–Ca–P–O system decreases with increasing oxygen potential. In fact, when p_{CO_2}/p_{CO} is 75·0, the composition range of the miscibility gap becomes very small. This is analogous to the effect of silica additions[4] to the Fe–Ca–P–O system melted in iron crucibles at 1400° C.

The separation of the iron–calcium phosphates into two liquids has a pronounced effect on the Fe^{3+}/Fe^{2+} ratio, as indicated by the following characteristics of the relationships in Fig. 2*a*.

(i) In the iron-oxide-rich phase (lower layer) Fe^{3+}/Fe^{2+} decreases with increasing proportions of calcium oxide

(ii) In the phosphate-rich phase (top layer) Fe^{3+}/Fe^{2+} increases with increasing concentrations of calcium oxide

(iii) For a given calcium oxide concentration, increase in CaO/P_2O_5 increases Fe^{2+}/Fe^{3+} in the bottom layer, whilst the reverse is the case in the phosphate-rich phase.

Larson and Chipman[5] investigated the ferric–ferrous iron reaction in Fe–Ca–Si–O melts at different oxygen potentials. The conclusion to be reached from the comparison of their results with the present data is as follows: for a given temperature, oxygen

Table VI

EXPERIMENTAL RESULTS ON Fe–Ca–Si–P–O SYSTEM AT 1550° C AND IN AIR

No.	Wt-%					Atom fraction						Calculated Values	
	CaO	FeO	Fe_2O_3	SiO_2*	P_2O_5	Ca^{2+}	Fe^{2+}	Fe^{3+}	Si^{4+}	P^{5+}	O^{2-}	4Si + 5P	$\frac{Ca}{4Si + 5P}$
P 1	11·17	18·89	58·27	4·60	7·07	0·0598	0·0790	0·2194	0·0230	0·0300	0·5888	0·242	0·25
2	17·47	15·95	45·79	9·73	11·06	0·0882	0·0629	0·1624	0·0458	0·0441	0·5966	0·404	0·22
Q 1	33·72	6·74	34·47	13·38	11·69	0·1619	0·0253	0·1163	0·0599	0·0443	0·5923	0·461	0·35
R 1	49·56	0·20	39·36	3·36	7·52	0·2494	0·0008	0·1391	0·0157	0·0299	0·5651	0·212	1·17

* By difference

Table VII
COMPOSITION RANGE STUDIED

		Wt-%				
		CaO	FeO	Fe_2O_3	SiO_2	P_2O_5
p_{CO_2}/p_{CO}	2·5	18–55	12–53	1–23	4–19	1–32
	11·4	16–48	11–48	8–35	3–21	1–19
	75·0	5–63	1–46	7–40	3–15	3–28
	air	11–50	0·2–19	34–53	3–13	7–12

potential, molar $CaO/SiO_2 = CaO/P_2O_5$, and calcium oxide concentration, the Fe^{3+}/Fe^{2+} ratio is much lower in the phosphate than that in the silicate. This is shown in Table VIII.

This characteristic difference between the interactions in iron–calcium silicate and those in iron–calcium phosphate melts is in line with the conclusions reached from the authors' previous work on molten iron silicates and iron phosphates. Although the plots in Figs. 2*a* and *b*, and those given previously for ternary melts,[1] reveal some interesting facts on some of the physico-chemical properties of these melts, application of this method of treatment of the data is not satisfactory for molten silicophosphates.

Iron–Calcium Silicophosphates

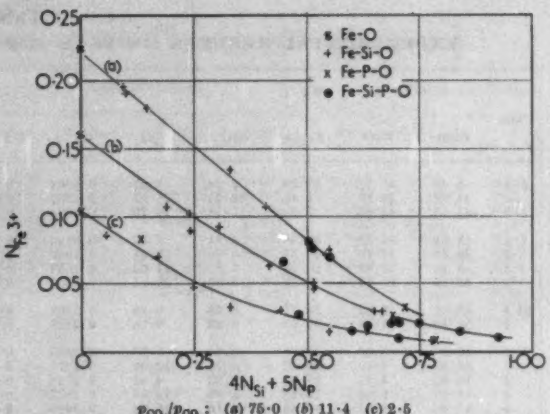
The reaction studied in this work may be represented by the expression

$$2Fe^{3+} + CO_3 = 2Fe^{2+} + O^{2-} + CO \quad \ldots\ldots(1)$$

For a given temperature and gas ratio, any change in composition of the melt changes the Fe^{3+}/Fe^{2+} ratio and oxide ion activity in the melt, because of the non-ideal behaviour of the system. In the iron–calcium silicophosphate system there are six components; the concentration of oxygen, however, is a dependent variable, as it must satisfy all the other elements to convert them to their respective oxides. For a given temperature and oxygen potential there are three independent variables, i.e. calcium, silicon, and phosphorus ion concentrations. Therefore a method must be sought whereby the variation in the state of iron (divalent or trivalent) with the concentration of the other independent variables may be represented graphically.

It is now a universally accepted view that in molten ferrites, silicates, phosphates, and their mixtures, silicon and phosphorus are bonded with oxygen ions forming network or ring-like anion complexes. Part of the trivalent iron is also co-ordinated in this anion complex formation and the remainder is in the cationic state. Whatever the state of these anion complexes may be, for thermodynamic purposes the composition of the melts may be represented in terms of the atomic fractions of constituent elements.

As already indicated, phosphates reduce the Fe^{3+}/Fe^{2+} ratio concentration more than the silicates. It is therefore necessary to discover a method whereby the combined effect of these two strong network-formers can be represented in a simple manner. As will be seen from the following illustrations, variation in the trivalent iron concentration may be related to the sum $4N_{Si} + 5N_P$, where N is the atom fraction of the element indicated by the subscript and the factors 4 and 5 are their valencies.



p_{CO_2}/p_{CO} : (a) 75·0 (b) 11·4 (c) 2·5

Fig. 3—Variation of ferric iron with silicon and phosphorus concentrations in Fe–Si–P–O system at 1550° C for p_{CO_2}/p_{CO} ratios as shown. Results taken from authors' previous data[1]

First, consider a simpler system, i.e. Fe–Si–P–O. From the results published previously,[1] in Fig. 3 $N_{Fe^{3+}}$ is plotted against $4N_{Si} + 5N_P$. An important feature of the relationship in Fig. 3 is that it applies to two ternary systems, i.e. iron silicate and iron phosphate, and their mixtures. Although there are only a few results available on the Fe–P–O melts, they conform to the same pattern. From this simple diagram it becomes possible to predict the concentration of trivalent iron, and hence divalent iron, for a given p_{CO_2}/p_{CO} ratio and concentrations of silicon and phosphorus atoms.

The plots in Fig. 4*a* are derived from the results of Larson and Chipman[5] on the Fe–Ca–Si–O system and those in Fig. 4*b* are from the present data on the Fe–Ca–P–O system, both in equilibrium with $p_{CO_2}/p_{CO} = 11·4$ at 1550° C. The discontinuity of the curves in Fig. 4*b*, shown by broken lines, indicates the miscibility gap. Comparing the two systems, it is seen that for a given $4N_{Si} = 5N_P$ and calcium content the concentration of trivalent iron is much less in the phosphate than that in the silicate. This is probably associated with the fact that the phosphorus ion is a stronger network-former than the silicon ion. The relationship in Fig. 4 for both systems is affected by Ca/Si or Ca/P ratios. In other words, divalent iron and calcium ions are not equivalent in their effects on the physico-chemical properties of these systems.

Table VIII
COMPARISON OF Fe^{3+}/Fe^{2+} RATIOS IN Fe–Ca–Si–O AND Fe–Ca–P–O MELTS FOR 1550° C AND $p_{CO_2}/p_{CO} = 11·4$

Molar $\frac{CaO}{SiO_2} = \frac{CaO}{P_2O_5}$	N_{CaO}	Fe^{3+}/Fe^{2+}	
		in Fe–Ca–Si–O*	in Fe–Ca–P–O†
2	0·2	0·68	0·16
2	0·4	0·89	0·085
4	0·2	0·76	0·27
4	0·4	1·14	0·19

* Derived from results of Larson and Chipman[5]
† Derived from results in Fig. 2a

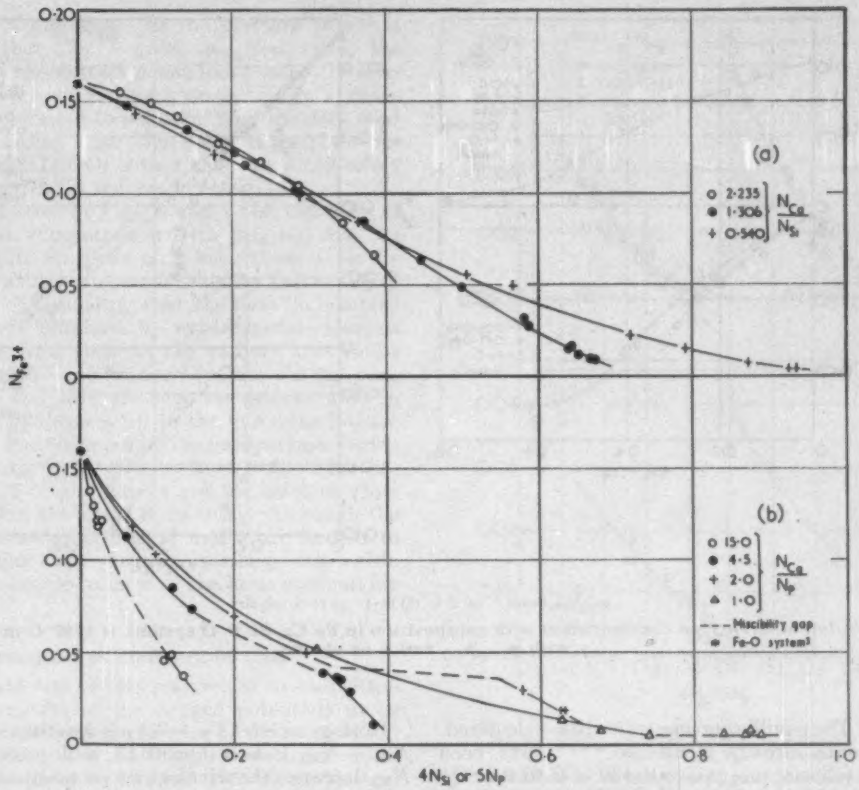


Fig. 4—Relationships between ferric–silicon and ferric–phosphorus ion concentrations in (*a*) Fe–Ca–Si–O system using data of Larson and Chipman,[5] and (*b*) Fe–Ca–P–O system using present data. In both cases p_{CO_2}/p_{CO} = 11·4, temperature 1550° C

From the data in Table II for the gas ratio 75·0 a plot similar to that in Fig. 4*b* is obtained, but for the sake of brevity it is not reproduced here. These curves, as would be expected, lie above those given in Fig. 4*b*, and below those which may be obtained (by interpolation) from the data of Larson and Chipman for the gas ratio 75·0.

In Figs. 5*a–d*, $N_{Fe^{3+}}$ is plotted against $4N_{Si} + 5N_P$ from the results in Tables III–VI for the gas ratios p_{CO_2}/p_{CO} = 2·5, 11·4, 75·0, and air. There are four important features of these relationships.

(i) For a given $N_{Ca}/(4N_{Si} + 5N_P)$ the concentration of the trivalent iron depends on the sum $4N_{Si} + 5N_P$ only, irrespective of the relative proportions of silicon and phosphorus atoms
(ii) For a given $4N_{Si} + 5N_P$ the concentration of trivalent iron decreases with increasing calcium content of the system
(iii) This effect of calcium becomes more pronounced as the oxygen potential of the system increases
(iv) For a given composition, the concentration of trivalent iron increases with increasing oxygen potential of the system.

Although only four experiments were carried out in air, the results in Fig. 5*d* conform to the pattern outlined for the less oxidizing conditions.

For comparison, the curves in Fig. 6 are reproduced from Figs. 4*a* and *b*, and 5*b* for $N_{Ca}/(4N_{Si} + 5N_P)$ = 0·4 It is interesting to note that the curve for the silicophosphate is slightly below but very close to that for the silicate melts. In the absence of silicon, however, there is a sharp drop in the trivalent iron concentration. This may indicate the presence of a much stronger atomic interaction in the silicate-free phosphates.

Complex Slags in Equilibrium with Iron

Fetters and Chipman,[6] Taylor and Chipman,[7] and Winkler and Chipman[8] equilibrated complex slags with liquid iron at several temperatures. The majority of their data fall within the range indicated in Table IX.

For the reaction

$$CO(g) + [O] = CO_2\,(g) \quad \ldots\ldots(2)$$

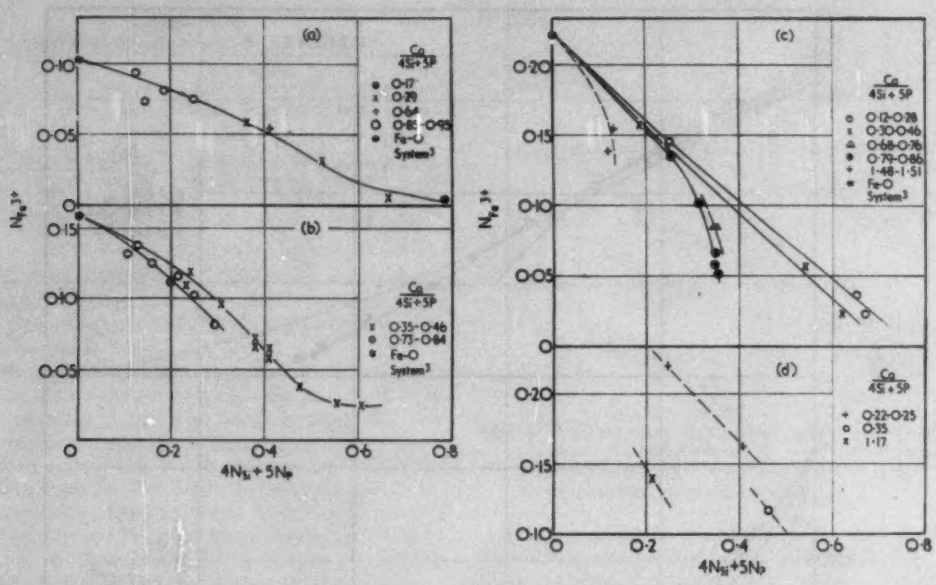
the following equilibrium constant has been derived by Gokcen[9] from his recent gas–metal equilibrium measurements.

$$\log K = \frac{8088}{T} - 4\cdot438 \quad \ldots\ldots(3)$$

where

$$K = \frac{p_{CO_2}}{p_{CO}} \times \frac{1}{[\%O]} \quad \ldots\ldots(4)$$

From the known oxygen content of the metal and its temperature, the value of p_{CO_2}/p_{CO} in equilibrium with metal and slag can be calculated from equations



p_{CO_2}/p_{CO} ratios : (*a*) 2·5 (*b*) 11·4 (*c*) 75·0 (*d*) air

Fig. 5—Variation of ferric iron concentration with composition in Fe–Ca–Si–P–O system at 1550° C in equilibrium with p_{CO_2}/p_{CO} ratios as shown

(3) and (4). The equilibrium gas ratios thus calculated, from the data already mentioned,[6, 7, 8] have been grouped as follows: $p_{CO_2}/p_{CO} = 0{\cdot}130 \pm 0{\cdot}014$, $0{\cdot}095 \pm 0{\cdot}015$, $0{\cdot}067 \pm 0{\cdot}006$, and $0{\cdot}052 \pm 0{\cdot}006$. In Fig. 7, $N_{Fe^{3+}}$ is plotted against $4N_{Si} + 5N_P$ for ranges of equilibrium gas ratios. Two points *F* in Fig. 7*d* are from slags containing some fluoride. In slags containing more than 1% of alumina and 4·6% of calcium fluoride, the concentrations of trivalent iron for a given $4N_{Si} + 5N_P$ are found to be much lower than those indicated by the curves in Fig. 7 (not included in the diagram). An important feature of the relationship in Fig. 7 is that, for a given p_{CO_2}/p_{CO} ratio, the atomic concentration of trivalent iron is a continuous function of only $4N_{Si} + 5N_P$, and the divalent cations, i.e. Ca^{2+}, Mg^{2+}, Mn^{2+}, and Fe^{2+}, are replaceable by one another, within the composition range given in Table IX.

In slags where $4N_{Si} + 5N_P$ is less than 0·10, and/or $N_{Ca} + N_{Mg}$ is less than 0·15, a decrease in $N_{Ca} + N_{Mg}$ decreases the trivalent iron concentration. When $4N_{Si} + 5N_P$ is higher than 0·60, there is a slight increase in the trivalent iron concentration with decreasing $N_{Ca} + N_{Mg}$. It should, therefore, be pointed out very clearly that simple relationships in Fig. 7 are for slag compositions within the range outlined in Table IX.

With reference to Fig. 5 it is seen that the plot is still independent of N_{Ca} at $p_{CO_2}/p_{CO} = 2{\cdot}5$, but with increasing gas ratio this simple relationship no longer holds, as seen in Figs. 5*b–d*. In the study of the factors influencing the slag–metal–gas sulphur reaction a similar phenomenon was observed,[10, 11] and the indications were that in complex systems the cations mentioned above, i.e. Ca^{2+}, Mg^{2+}, Mn^{2+}, and Fe^{2+}, are equivalent also in their effects on the oxide

Table IX

COMPOSITION RANGE OF SOME COMPLEX SLAGS STUDIED

		Wt-%		Atom Fraction	
Temperature	1530–1715° C	CaO	11·7–46·2	Ca	0·050–0·21
[%O] in metal	0·045–0·240	MgO	0·1–22·6	Mg	0·001–0·13
		MnO	0·0–13·0	Mn	0·000–0·05
$N_{Ca} + N_{Mg}$	= 0·15–0·25	FeO	3·0–61·7	Fe^{2+}	0·010–0·27
		Fe_2O_3	0·7–13·5	Fe^{3+}	0·002–0·05
$4N_{Si} + 5N_P$	= 0·10–0·60	SiO_2	5·0–36·5	Si	0·025–0·15
		P_2O_5	0·0–19·2	P	0·000–0·07
		CaF_2	0·0– 4·6	F	0·000–0·03
		Al_2O_3	0·0– 0·8	Al	0·000–0·01

ion activity of the slags. In the previous paper[1] it was shown that, for a given p_{CO_2}/p_{CO} ratio, the trivalent iron concentration was independent of temperature. Hence, no further comments will be made on this subject except to point out that the data used for the plots in Fig. 7 are from melts at temperatures from 1530° to 1715° C; within this range the effect of temperature could not be detected.

From the curves in Figs. 5 and 7 the variation of trivalent iron concentration with p_{CO_2}/p_{CO} may be derived. Figure 8, drawn on a logarithmic scale for convenience, shows this relationship for five values of $4N_{Si} + 5N_P$. Considering that the data on complex slags[6, 7, 8] were obtained by experimental methods very different from those of the authors, the results agree well with one another (points for p_{CO_2}/p_{CO} = 2·5, 11·4, and 75·0 are from the present work in Figs. 5*a–c*). The curves up to the gas ratio 2·5 are for calcium and magnesium concentrations falling within the range $N_{Ca} + N_{Mg} = 0·15–0·25$. For gas ratios above 2·5, the curves are for calcium atom fractions within the range 0·20–0·25. Although the simple relationships in Figs. 7 and 8 are limited to certain complex slags, their compositions fall within the range applicable to most of the basic steelmaking practices.

Practical Application of Equilibrium Data

The ultimate aim of this research is to enable the accurate estimation of the oxygen potentials to be made from an adequate knowledge of the composition of the steelmaking slags. Although there are accurate data on the activity of ferrous oxide in simple and complex slags in equilibrium with liquid iron,[6, 7] divergent opinions[12, 13] were put forward on the method of relating the variation of the ferrous oxide activity with the composition of the slag containing seven constituent oxides. These data, in their present form, cannot be used satisfactorily for the accurate

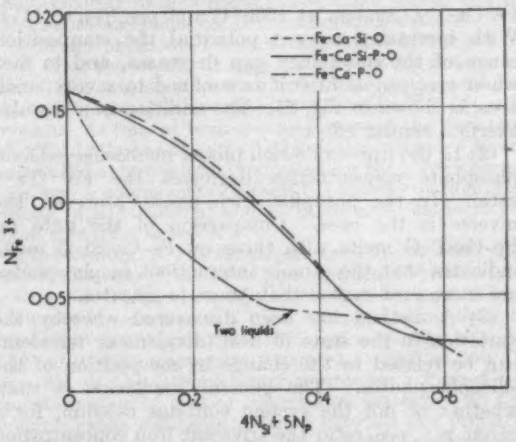
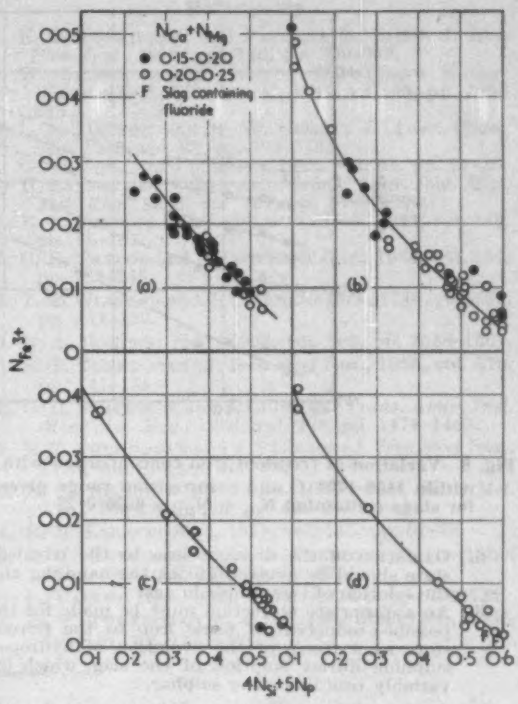


Fig. 6—Comparison of molten Fe–Ca–Si–O, Fe–Ca–P–O, and Fe–Ca–Si–P–O systems for the conditions $p_{CO_2}/p_{CO} = 11·4$, temperature 1550° C, and $N_{Ca}/4N_{Si} + 5N_P = 0·4$



p_{CO_2}/p_{CO} ratios (*a*) 0·130 ± 0·014 (*b*) 0·095 ± 0·015 (*c*) 0·067 ± 0·006 (*d*) 0·052 ± 0·006

Fig. 7—Variation of trivalent iron concentration with silicon and phosphorus contents of complex slags in equilibrium with liquid iron and p_{CO_2}/p_{CO} ratios as shown

estimation of the ferrous oxide activity or the oxygen potential of complex steelmaking slags.

The important outcome of the present work is that the oxygen potential of complex slags can be evaluated accurately over a wide composition and temperature range, i.e. within the composition range given in Table IX and those studied by the authors, and from 1500° to 1700° C. If the atomic fractions of trivalent iron, silicon, and phosphorus are known, the p_{CO_2}/p_{CO} ratio in equilibrium with the system can be evaluated from Fig. 8. Inserting this gas ratio in expression (4) the oxygen content of the metal in equilibrium with the slag can be determined for any temperature.

To calculate the atom fractions of the three elements under consideration, it is necessary to have a complete analysis of the slag. If, however, in a given refining practice the composition of the slag does not vary a great deal, then the total number of atoms may remain about the same. This possible simplification will mean that the oxygen potential of a steelmaking slag may be estimated from the knowledge of trivalent iron, silicon, and phosphorus concentrations, and temperature.

It should be pointed out that special care must be practised in the analysis of the slag for ferric iron. There are three precautions to be observed:

(i) Oxidation of the slag sample during cooling should be prevented by well-developed sampling methods

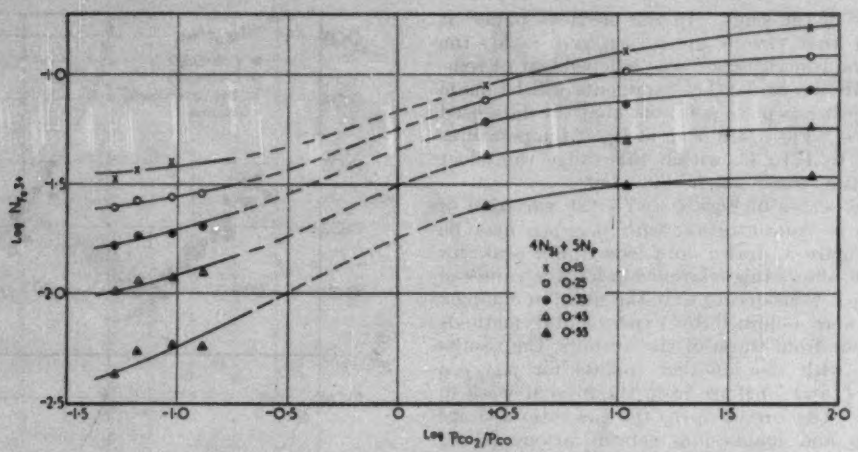


Fig. 8—Variation of trivalent iron concentration with p_{CO_2}/p_{CO} at various values of $4N_{Si} + 5N_P$ in complex slags within 1500–1700° C and composition range given in Table IX. For gas ratios higher than 2·5, curves are for slags containing $N_{Ca} + N_{Mg} = 0·20–0·25$

(ii) Oxidation of the divalent iron to the trivalent state should be avoided during the handling and the solution of the sample in acid

(iii) An appropriate correction must be made for the possible reduction of ferric iron to the ferrous state as a result of the evolution of hydrogen sulphide during solution of the slag, which invariably contains some sulphur.

Another possible application of the present data is to compute a slag composition which will have a desired oxygen potential at a given temperature. The method of operation here is the reverse of the one already discussed. After fixing the oxygen potential or equivalent oxygen content in the metal, calculate the corresponding p_{CO_2}/p_{CO} ratio for the required temperature. For given concentrations of N_{Si} and N_P, one can now obtain the value of $N_{Fe^{3+}}$ from Fig. 8. The next step is to calculate the proportions of the other constituents of the slag so that the atom fractions of silicon, phosphorus, and trivalent iron will be the same as those fixed previously. Obviously this is a very tedious computation and will have no practical use except in very special cases.

The only feasible approach to this problem is the preparation of a 'log sheet' covering a sufficient range of slag composition arranged in a suitable manner. For each composition the oxygen potential should then be calculated by means of the data presented in this paper. Then it will be possible to read off directly the oxygen potential of any particular slag by matching, as closely as possible, the composition of the slag with that in the calculated chart. Considerations are now being given to the preparation of what might be called an 'oxygen potential chart' on the lines indicated.

Although part of the diagram in Fig. 8 may be regarded as somewhat uncertain (indicated by broken lines) for steelmaking conditions the values of log p_{CO_2}/p_{CO} fall within the range $-0·8$ to $-1·4$ for which there are sufficient data to ascertain the position of the curves in Fig. 8.

When the 'oxidizing power' of a slag is evaluated quantitatively in any one particular term, e.g. in terms of oxygen potential (calories), partial pressure of oxygen (atm or mm Hg), p_{CO_2}/p_{CO}, p_{H_2O}/p_{H_2}, [%O] or in any other suitable term, it then becomes possible to study more accurately the conditions affecting the distributions of manganese, phosphorus, sulphur, etc. between metal and slag under various operating conditions. This possible application also includes the oxygen-blowing processes where the slags have much higher oxygen potentials than those normally encountered in the other steelmaking processes. Attention should also be drawn to the fact that [%O] calculated from slag composition will not necessarily agree with the actual oxygen concentration in the metal, if the metal contains more than about 0·05% carbon. This phenomenon was discussed in detail in previous publications.[14–17]

CONCLUSIONS

(1) There is a large miscibility gap in the molten Fe–Ca–P–O system at 1550° C and $p_{CO_2}/p_{CO} = 11·4$. With increasing oxygen potential the composition range of the miscibility gap decreases, and in fact when $p_{CO_2}/p_{CO} = 75·0$ it is confined to a very small area as shown in Fig. 2*b*. The addition of silica also exerts a similar effect.

(2) In the iron-oxide-rich phase, increasing calcium phosphate concentration decreases the Fe^{3+}/Fe^{2+} ratio. In the phosphate-rich phase, however, the reverse is the case. Comparison of the data on Fe–Ca–P–O melts with those on Fe–Ca–Si–O melts indicates that the atomic interactions in phosphates are more pronounced than those in silicates.

(3) A method has been discovered whereby the variation in the state of iron (divalent or trivalent) can be related to the change in composition of the silicophosphates. The general conclusion is that, whether or not the system contains calcium, for a given p_{CO_2}/p_{CO} ratio the trivalent iron concentration is a continuous function of $4N_{Si} + 5N_P$, irrespective of the relative proportions of silicon and phosphorus. In the presence of calcium, this relationship is also affected by $N_{Ca}/(4N_{Si} + 5N_P)$ ratio. When the

oxygen potential is reduced, i.e. at and below $p_{CO_2}/p_{CO} = 2{\cdot}5$ at temperatures from 1500° to 1700° C, this effect of calcium is not detectable.

(4) Study of the available data on complex slags in equilibrium with liquid iron indicates that the atomic concentration of trivalent iron varies solely with the sum $4N_{Si} + 5N_P$ within the temperature and composition range stated in Table IX. Under these conditions, the divalent cations Ca^{2+}, Mg^{2+}, Mn^{2+}, and Fe^{2+} appear to be equivalent in their effects on the concentration of trivalent iron.

(5) When $N_{Ca} + N_{Mg} < 0{\cdot}15$, and $4N_{Si} + 5N_P < 0{\cdot}10$, the ferric iron concentrations become lower than those indicated by the curves in Fig. 7. High percentages of calcium fluoride and alumina also exert a similar effect. The data available do not indicate the lower limit below which the influence of alumina and calcium fluoride may become negligible. However, the lower limit for calcium fluoride may tentatively be set at about 4–5%, and for alumina 1·0%.

(6) From the relationship in Fig. 8 it now becomes possible to estimate the oxygen potential of most of the steelmaking slags falling within the range stated in the paper.

Acknowledgment

The authors wish to thank Miss B. Farrell for her assistance in some of the experimental work.

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Correspondence on the Paper—

A High-temperature X-ray Study on High-speed Steel*

By H. J. Goldschmidt

Monsieur **A. Michel** (Chambre Syndicale des Producteurs d'Aciers Fins et Spéciaux, Paris) wrote: The technique of X-ray examination at high temperatures is a valuable help in the study of tempering phenomena. With my colleague Jean Papier, at the Laboratoire de Métallurgie de l'Ecole Nationale Supérieure des Mines de Saint-Etienne, I have, on behalf of the Institut de Recherches de la Sidérurgie, carried out researches on the tempering of high-speed steels, and I should like to offer some comments on Dr. Goldschmidt's paper.

I do not understand certain indications in Table I of Part II of the paper. It suggests that for the temper at 600° C one obtains, from the start of time at temperature, the total quantity of α possible (70%), whilst 12% of γ still remains. As time at temperature increases, the quantity of γ diminishes in favour of that of the carbides. Even within the approximation indicated for the given values, this fact is anomalous. In fact, the transformation of γ results in α + carbide, and so there must be as much more α as there is less γ.

Furthermore, if I understand correctly, at 500° and 550° C the author indicates that the transformation of γ to α takes place into α_M, that which he calls 'high-temperature martensite'. For example, after 8–10 h holding at 500° C one finds 63% α_M, consisting thus of 55% of quench martensite tempered at 500° or 550° C, plus 8% of 'high-temperature martensite', formed by transformation of part of the residual austenite. In his opinion, what difference is there between the primary quench martensite after tempering, and this martensite formed by isothermal transformation of austenite?

On p. 80, the author reports on the conventional treatment of high-speed steel, which consists, after hardening, of one or two tempers of 2 or 3 h at 550–565° C. This tempering must bring about the transformation of the residual austenite to martensite through *secondary quenching* in the course of cooling. But the text appears to say, if we are not mistaken, that the transformation takes place *at the tempering temperature*, which would certainly not give the required hardness.

The author asks (p. 80) whether austenite decomposes during cooling or isothermally at the temperature of tempering. There is no doubt, in our opinion, that it decomposes by both processes, depending on the conditions, temperature, and time of tempering. But in order to produce the required hardness, it must decompose during cooling. In our experience, it seems that the secondary hardening is produced simultaneously by the secondary quench and by an isothermal phenomenon which we think is precipitation hardening, the second hardening being roughly double that of the first.

If we understand the ideas of the author (p. 81), the residual austenite *during the period at constant temperature* (and not after tempering) transforms to 'high-temperature martensite' α_M, that is to say, to a phase which is essentially of the same composition as the parent austenite, and this state would last for more than 190 h at 500° C. Such an explanation of the X-ray observations seems to us to be quite abnormal. In fact, the observations show that the quench martensite has already undergone decompositions during tempering at temperatures. Why should it form in any way at temperatures of the order of 500° C and more? We should be glad if the author would tell us exactly what he understands by α_M: what is its composition? Has it carbon in solution? Is its crystal system tetragonal or cubic?

* *J. Iron Steel Inst.*, 1957, vol. 186, May, pp. 68–85.

If it is cubic, it is a supersaturated ferrite. What difference is there in Table I between a_M and a_F?

In studies which have not yet been published, we have found by dilatometric experiments that isothermal tempering at 700° C of a quenched 18–4–1 steel first produces a dilatation and then a contraction. Heating to 700° C has already produced a dilatation (preceded first by dilatation and then by contraction). Isothermal dilatation at 700° C is the remains of the second dilatation, observed during heating. The subsequent contraction does not seem to cease until after 15 h.

The experiments of Dr. Goldschmidt described in Part I of his paper show that in Series *A* (after 2 h of tempering at 700° C), the parameters of a are always larger than those of series *B* (after 7 days of tempering at 700° C). Thus after 2 h of tempering at 700° C the ferrite still remains supersaturated, which confirms our hypothesis that the observed contraction was produced by precipitation out of the ferrite, the composition of which tends towards that of the annealed steel.

During the isothermal temperings, has the author measured the changes in parameter of the tempered quench martensite and of the residual austenite?

AUTHOR'S REPLY

Dr. **H. J. Goldschmidt** (B.S.A. Group Research Centre) wrote: I think the definition of 'a_M' in Table I (Part II) may have been misunderstood; a_M is the total body-centred constituent present, part of which is still equi-compositional with γ; the 70% a quoted under 600° C in the Table thus contains a portion, which, as regards composition, could effectively still be considered under γ; with time there is a change *within* a_M of the relative proportions of freshly formed and partially decomposed martensite. The progress of this change is indicated by the increasing carbide content. 'a_M' therefore conceals these two components, a subdivision which could not be brought out in Table I. The Table merely intends to record the empirical X-ray observations of total phase-amounts; the a portion stands for the entire amount of phase of body-centred structure present, of whatever composition or degree of tetragonality.

Referring to M. Michel's next point, the term 'high-temperature martensite' was meant to refer to the actual condition at and near the Ac_1 temperature only; it was introduced later to help in the more detailed discussion, and not to be directly applied to the observational 500° and 550° C temper data of Table I. I suggest that the 63% a_M after 8–10 h tempering can only very formally be subdivided into the 55% and 8% which M. Michel mentions; the difference has, I think, mainly a meaning as a matter of phase-history in that one component was that originally present as quench martensite, the other being that derived from the transforming austenite. In effect, the whole of the 63% a_M referred to may physically show little difference, although the advancement of breakdown would have reached varying stages within the mass.

To the third point I would reply that the transformation of residual austenite takes place by *both* processes, i.e. isothermally (as is here certainly observed) *and*, as M. Michel says, through secondary quenching; I quite agree that the latter would be the major cause of the hardness, but some of it can, I suggest, also be contributed by the martensite isothermally formed.

I absolutely agree that both the isothermal and athermal decompositions of austenite apply, and, in fact, tried to say so; M. Michel's experience in this connection is most interesting.

It is *not* implied (p. 81) that the residual austenite, after transforming to a_M, then remains of the same composition. It certainly decomposes slowly, and after the temper of 190 h at 500° C (the case M. Michel refers to) it is quite agreed that a substantial composition change within the quench martensite will have occurred; this is in fact said on p. 80, and is also implied by the carbide increase shown. I trust this will also answer the several questions M. Michel asks in this connection. Even after 190 h, whilst some residual austenite is still present, there is a continuous supply of freshly formed martensite, some of which may only have been produced within the last hour and thus be in the earliest stages of carbon-loss.

By 'a_M' in this context was understood the total martensite present, of compositions ranging from that of transformed austenite to that in an advanced stage of decomposition, though short of ferrite. It certainly has carbon in solution. The difference from 'a_F' lies in its state of heterogeneity on a lattice scale and of internal strain, as manifested by line-broadening. Ferrite is considered substantially homogeneous in composition and of low carbon content; it is, as M. Michel says, cubic, and a_M is tetragonal, but in high-speed steel the axial ratio is so near 1·0 that line broadening tends to mask this. It is agreed that the borderline between a_M and a_F is not necessarily a well defined one.

Regarding M. Michel's last point, I was very pleased to learn that his dilatometric results at 700° C are in such good concord with our findings of Part I. Both certainly give evidence that ferrite can be supersaturated and that precipitation can occur within it. The changes in parameter of martensite and residual austenite were not measured in the temper series.

ERRATA

Dr. **Goldschmidt** wrote: This note is to correct an error found in the above paper, and pointed out by the kindness of G. Hoyle and K. A. Ridal of B.I.S.R.A., Sheffield.

It is that, on the X-ray diffraction pattern of η-carbide (*see* p. 69, 2nd paragraph), the reflections ascribed the indices '(12, 3, 0)' and '(12, 2, 0)' ($\Sigma h^2 = 153$ and 148) should have been (12, 2, 2) and (777) ($\Sigma h^2 = 152$ and 147) respectively. Indices (12, 3, 0) and (12, 2, 0) are in fact excluded by space-group considerations. This error, which is much regretted, had already occurred in an earlier paper (*J. Iron Steel Inst.*, 1952, vol. 170, p. 189) and escaped notice, and has unfortunately been taken over to the recent work. The substance of the papers, however, and the conclusions are not affected.

The amendments required are as follows. The lattice-spacings given for η-carbide should be lower throughout by 0·33%, or by 0·037kX (within the present accuracy). Thus the values in Table I (Part I), column 'η,' should be decreased by this amount: viz. for 11·064 read 11·027kX, etc. In Figs. 1 and 2, the atomic volumes for η-carbide should be lower by 1·0%, so that the curve for η should be displaced downwards parallel to itself and to the ordinate axis by an amount of 0·12kX. The same applies to Fig. 5. The gradient and shape of the curves is not affected by any significant amount. The expansion *coefficients* of η-carbide given are not affected, nor are Figs. 3 and 4. The only amendment required in Part I is on p. 73 (1st column, 3rd paragraph, 1st line), which should read: "Since the ratio A_α/A_η is 0·983 . . ." This makes no subsequent difference to the text.

In Part II, the only change required is on p. 83 (1st column, 2nd paragraph), where the figures should now read: "2·8643/11·036kX and 2·8630/11·075kX," and in Table II, where the η spacing values should also be lowered by 0·037kX.

The same decrease of all η-carbide lattice dimensions cited applies to the 1952 paper, where, however, it again does not alter the conclusions.

Correspondence on the Paper—The Effect of Cold Work on the Creep-Rupture Properties of a Series of Simple 18/8 Stainless Steels*

By F. B. Cuff and N. J. Grant

Dr. **A. J. Lena** and Mr. **R. A. Lula** (Allegheny Ludlum Steel Corporation) wrote: We have recently reported on the elevated-temperature-properties of cold-rolled commercial stainless steels[1] and certain differences which appear to exist between our work and that of Cuff and Grant are worth mentioning here. The steels examined were:

A.I.S.I. Type	C, %	Si, %	Mn, %	Cr, %	Ni, %	N_2, %
301	0·11	0·30	0·76	17·83	7·17	0·046
305	0·072	0·31	1·04	17·79	11·58	0·052
310	0·065	0·35	1·40	19·86	19·86	0·050

These steels are such that they cover the common structural changes which occur in austenitic stainless steels. Type 301 transforms partially to martensite during cold-rolling, whereas the other two grades are sufficiently stable to remain completely austenitic. Carbide precipitation in the temperature range 1000–1600° F occurs in all three steels, but only in type 310 does extensive sigma formation take place.

The work which we have done has indicated that recrystallization is the major structural change which affects the stress-rupture properties of cold-rolled austenitic stainless steel, regardless of other structural changes such as carbide precipitation or sigma formation. We have, however, observed that recrystallization has a pronounced effect on these other structural changes and, unless proper etching procedures are used to show recrystallization, erroneous conclusions can be made regarding structural changes as they effect stress-rupture properties. For instance, we did not observe any breaks in the rupture curves due to carbide coalescence and as a result of the higher carbon content the rupture strengths at 1200° F of 30% cold-rolled types 301 and 305 are significantly higher than any of the steels used by Cuff and Grant. This is true for both the 100-h and 1000-h rupture life. We have, however, observed that recrystallization has a marked effect on the distribution of carbide precipitates, as can be seen in Fig. *A*. There is an apparent resolution of much of the carbide while the carbides which remain in the recrystallized region coalesce. The break in the rupture curve, when this occurs, is due to recrystallization and not to carbide coalescence. Our work, in contrast to that of Cuff and Grant, would indicate that a high carbon plus nitrogen content such as is found in commercial steels is desirable for rupture times of at least 1000 h.

The break in the rupture curves of steels 4 and 6 which were cold-rolled 35% and tested at 1200° F has been attributed by the authors to the formation of sigma. Since these breaks did not occur in the 25% cold-worked samples of the same steels at 1200° F, it can be assumed that the faster rate of formation of sigma was due to the additional cold-work. We have found, in both unstressed aged samples[2] and in fractured stress-rupture test pieces, that the accelerated formation of the sigma phase due to cold-working is caused by recrystallization. In stress-rupture testing this effect produces a microstructure similar to that shown in Fig. *B*. This photomicrograph gives the appearance that sigma has formed at the grain boundaries of the cold-rolled austenite grain boundaries. With proper etching, however, it can be shown that the sigma forms as a result of recrystallization which is initiated at the grain boundaries; this can be seen in Fig. *C*. In aged type 310 this effect was found over the entire temperature range studied, 1250–1600° F. We have observed this condition in stable austenitic chromium–manganese steels as well as type 310 and have referred to it as a 'recrystallization transformation.' The breaks in our rupture curves on type 310 were due to this transformation, and we believe the most important effect is recrystallization rather than sigma formation.

The authors make the statement that the stable austenitic steels do not recrystallize at 1200° F in less than 1000 h. We have not found this to be the case in commercial steels. Figure *D* is a photomicrograph of 30% cold-rolled type 305 which fractured in 807 h at 1200° F with a stress of 25,000 lb/in². The recrystallization at the grain boundaries is obvious. In the case of type 305 at 1200° F, samples cold-rolled 50% recrystallize in less than 10 h, while those cold-rolled 30% require about 800 h. In the case of type 301 cold-rolled 40%, recrystallization begins in about 30 h at 1200° F. Because of these data, as well as the effect of cold-work on the acceleration of sigma formation, we wonder if the breaks in the rupture curves of steels 4 and 6 at 1200° F could have been caused by recrystallization?

In spite of the difference in austenite stability of types

* *J. Iron Steel Inst.*, 1957, vol. 186, June, pp. 188–197.

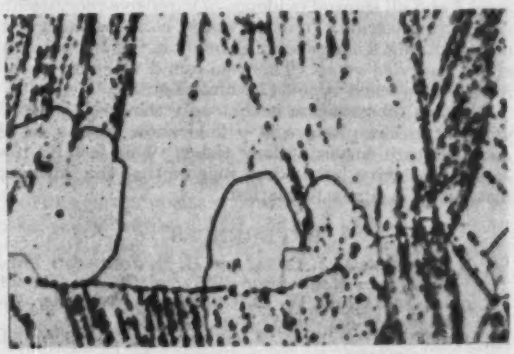

Fig. A—Cold-rolled type 305 aged for 100 h at 1350° F, showing carbide resolution of recrystallized regions. Etched electrolytically in NaCN and HNO_3 × 2000

Fig. B—Sigma formation in a 40% cold-rolled type 310 stress-rupture specimen, fractured at 1350° F in 11·5 h at a stress of 25,000 lb/in². Etched electrolytically in NaOH × 500

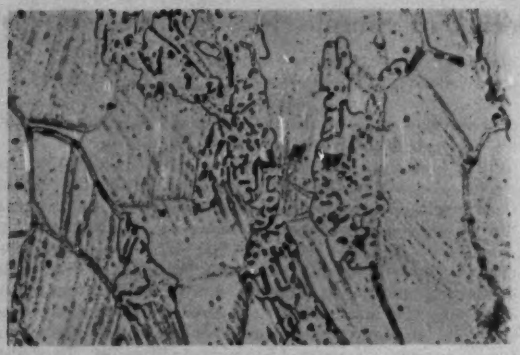

Fig. C—25% cold-rolled type 310 sample aged 24 h at 1475 F, showing sigma formation in recrystallized areas at the prior grain boundaries. Etched electrolytically in 10% oxalic acid × 500

Fig. D—Grain-boundary recrystallization in a stress-rupture specimen of 30% cold-rolled type 305 fractured in 807 h at 1200°F with a stress of 25,000lb/in². Etched electrolytically in HNO_3 × 500

301 and 305, we have found that the effect of cold-rolling on the elevated-temperature properties of these two steels is almost identical. For maximum rupture strength in 100 and 1000 h at 1200° F, 30% cold reduction is an optimum amount for both steels. Furthermore, the rupture strengths at 1200° F for the two steels with 30% cold-work are very similar, being about 32,000 lb/in² for rupture in 100 h and about 24,000 lb/in² for rupture in 1000 h. It is perhaps surprising that these steels should behave so similarly in view of the different initial structure. However, the amount of martensite produced in type 301 by cold-rolling 30% is about 20%, with the balance being highly strained austenite. We have found that the martensite in type 301 transforms to austenite on slow heating at temperatures below 900° F. Thus, at 1200° F, type 301 is completely austenitic and hence is not too much different from type 305.

AUTHORS' REPLY

Professor **N. J. Grant** and Dr. **F. B. Cuff** (Massachusetts Institute of Technology) wrote: With regard to the optimum level of carbon plus nitrogen for creep resistance of stainless steels, two not unrelated statements were made: on the one hand, we stated that a minimum (for example, less than 0·02%) carbon + nitrogen content should be chosen to avoid the weakening effects of carbide growth and coalescence at long times. On the other hand, Lena and Lula stated that a high carbon + nitrogen content, such as found in commercial steels, is desirable for rupture times of at least 1000 h. The authors believe that both of these statements are correct and offer as evidence the information contained in papers by Hum and Grant[3] and Monkman and Grant.[4] The pertinent conclusion in these papers was that stainless steels tested in the temperature range 1000–1300° F show a minimum in creep resistance and rupture life when they contain 0·03–0·07% carbon + nitrogen, depending on stress and temperature. The steels in our paper contained 0·04–0·07% carbon + nitrogen, thus placing them in this minimum creep-resistance range, while the steels of Lena and Lula's tests contained more than 0·1% carbon + nitrogen, where they would be expected to have improved properties. Thus, if the carbon + nitrogen content of our steels were to be adjusted sufficiently in either direction, it is expected that the creep resistance would improve.

The longer time breaks in the creep-rupture curves of steels 4 and 6, cold-worked 35% and tested at 1200° F, were attributed to sigma-phase growth on the basis of the identification of this phase in the electrolytically separated residue of the tested specimens. Furthermore, photomicrographs of these steels (after an electropolish and electroetch in a chromic-oxide–glacial-acetic-acid solution) gave no evidence of recrystallization. It must be admitted, however, that Lena and Lula's photomicrographs of steels with not entirely similar composition can be interpreted as showing the presence of both recrystallized grains and sigma precipitation within these grains. However, we think that the observation of the simultaneous presence of recrystallization and a precipitation is not sufficient to label one as the cause of the other. Thus, while Lena and Lula state that "sigma forms as a result of recrystallization", it could be argued conversely that sigma precipitated at the grain boundary first and that the resulting depletion of the local matrix lowered the recrystallization temperature sufficiently to allow recrystallization to occur. Moreover, there is abundant evidence of sigma formation without recrystallization. In the latter case, recrystallization would be an instability of secondary importance since it occurred only as a result of an earlier instability (i.e. sigma formation). The point is that the cause and effect relationship between these two phenomena is not clear and that it is premature to assign a fundamental role to either.

However, there is another argument to suggest that sigma formation is the primary cause of the observed breaks in the creep-rupture curves. It will be noted that steels 1, 2, 3, and 5 showed no equivalent break in spite of the fact that they all have a lower alloy content than steel 6 and all showed evidence of extensive recrystallization during testing. In other words, recrystallization can occur without a corresponding break in the creep-rupture curve and vice versa. This was found to hold true also for a cold-worked type 347 stainless steel.[5]

The final observation is that only the steels which lie within the two-phase $\alpha + \gamma$ field show breaks in the creep-rupture curves at long times. This fact by itself is not conclusive but it does suggest that the important instability is sigma formation.

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4. F. C. Monkman and N. J. Grant: *Iron Age*, 1956, vol. 177, 31st May, p. 67.
5. N. J. Grant, *et al.*: *Trans. Amer. Soc. Metals*, 1956, vol. 48, pp 446–454.

IRON AND STEELWORKS ENGINEERING

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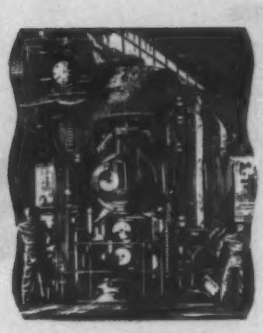

Translator Control

By W. N. Jenkins, B.Sc.(Eng.), A.M.I.E.E.

SYNOPSIS

The manipulation and control of steelworks plant is often a very complicated task requiring much skill and experience on the part of the operator. For example, a primary rolling mill may be rolling two different sizes of ingot down to blooms having a range of cross-sections involving ten different widths and four different heights. There may also be three different qualities of steel, each requiring a different number of passes through the mill. This gives a total of 240 different requirements. In each case the operator's task is to take the information given him and *translate* it into the necessary series of actions which may consist of adjusting the rolls before each pass to the correct distance between 48 in. and ¾ in. apart and then inserting the ingot into the right one of five grooves or 'holes' cut in the rolls. Not only has the operator to cope with a large number of requirements, but he must select in each case the appropriate course of action out of the large number of choices made possible to him by the controls at his disposal.

This formidable task is made easier for him by instruction and experience, but it is possible to completely relieve him of it by a form of automatic control which will unambiguously translate each requirement into the appropriate series of mill operations. The B.I.S.R.A. translator control, based on the use of 'motor uniselectors,' is designed to do this. Although translator control was developed initially for the primary rolling mill, it is now realized that its field of application is much wider. 1514

Introduction

ONE OF THE DISCOVERIES which made automatic controls practicable was the principle of 'closed-loop' control. It is because regulators embodying this principle are used that one frequently sees in steelworks such variables as the temperature of furnaces, strip tension on coilers, tandem-mill stand speeds, all maintained constant as near as the eye can see and for as long as the operator requires.

The principle is a simple one. A signal representing the departure of the variable from the required value is derived, amplified, and used to operate the plant to correct the departure. Because of the importance of the departure or error signal, such closed-loop controls are sometimes called 'error-operated regulators.'

Although many such regulators are to be found in steelworks, it is surprising that one of the most useful and spectacular forms of closed-loop control, namely remote position control, has not yet been widely applied. With remote position control, it is the position of a moving member which is maintained constant, or varied according to the operator's requirements.[1] Thus, in the case of a primary steel rolling mill or blooming mill, in which the distance between the rolls is varied by 'screwdown' motors, the operator with remote position control only has to select the distances required between the rolls and they follow up and find that position automatically in the minimum time. Without remote position control, the operator has to watch the screwdown dial and use his judgement to switch off when the correct position is approached, just as the furnace operator, in the old days, had to watch his temperature indicator all the time during changing conditions.

Another important step forward in the field of automatic control was the advent of the programming device. A programming device, generally speaking, is one which enables the operator to select a group of settings for the plant which can be applied simultaneously or sequentially under his direction, or automatically by the plant. Such a device, used in conjunction with remote position control, releases the operator from practically all routine work.

PROGRAM CONTROL OF INPUT SIGNALS TO CLOSED-LOOP SYSTEMS

The group selection of those settings which are used in sequence in a process is a powerful means of improving the consistency and speed of operation, and of reducing the operator's routine tasks. In the case

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The author is with the Electrical Engineering Section of B.I.S.R.A.'s Plant Engineering Division.

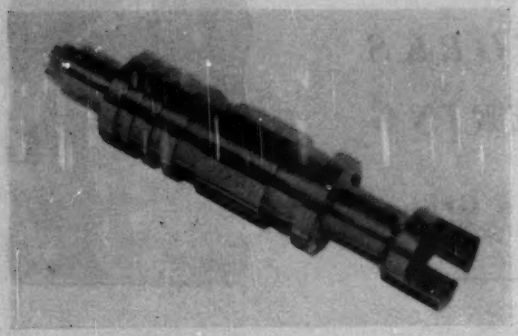

Fig. 1—Roll for a typical blooming mill

of the primary rolling mill it is possible to select not only groups of screwdown settings (one setting for each pass), but also groups of settings of the other rolling mill auxiliary motions which can be adapted for remote position control. Furthermore, the principle need not be applied only to remote position controls, but also to other forms of closed-loop control such as those used for regulating tension, speed, and temperature. Even the furnace could benefit from group selection of settings under certain circumstances (e.g. when a considerable number of cycles of temperature changes is required).

There are two ways possible for setting up a sequence of operations. The first is to set up in advance each setting on a series of rheostats, and during the process to connect voltages across each of these in turn to the remote position control. If frequent changes of program are required, such schemes tend to increase and not to decrease the amount of work of the operator but a variation of the method, practical in cases where changes are not frequent, is of some importance. In this it is arranged that the manual operation of the remote position controls during the processing of the first job effectively sets the rheostats mentioned above, in readiness for all subsequent similar jobs.

The second way of setting up a sequence of operations is to select a block of settings from a collection of them held, as it were, 'in stock.' Often, the required variation of product and unwanted changes in the process make the number of different blocks, or programs, to cover all eventualities very large and if the system is not to be restricted to often-repeated orders and completely straightforward processing, all these programs must be held in store.

In the case of rolling mills it is not always possible to select a complete program of rolling passes in advance of the arrival of the ingot to be reduced. The initial temperature of the ingot might be high, or low, or uneven, or the ingot might have some defect requiring special attention. The program selection must therefore be carried out by the operator immediately before the rolling of the ingot, or even after one or two passes have been made and he has acquired more information about the ingot from observing his main driving motor load ammeter. It must thus be possible to change the program easily and at a moment's notice.

Programs can be stored on punched cards or punched paper tape but in the case of the rolling mill the method presents difficulty on the above counts, especially when there is a large number of programs.

A deck of cards or a length of tape can be prepared in advance to cover the operation of the plant only if there is not likely to be any subsequent change affecting the program, in the plant itself. It is true that the number of choices of program is limited just before and during rolling, so that the operator can be supplied with a relatively small number of cards for each ingot, but experience has shown[2] that the handling of punched cards (even steel ones) by rolling-mill operators is unsatisfactory.

An alternative method of storing programs, with the big advantage that any program is immediately available, has been developed by B.I.S.R.A. and is called Translator Control.

TRANSLATOR CONTROL

With translator control, the operator has a small desk with several dial-selector switches called 'input switches' which he has to set before processing a particular job. Each input switch corresponds with some quantity or fact connected with the process. The set of facts and quantities registered on these switches must be adequate to cause the particular program associated with the job to be selected, but this is the only requirement. It is thus only necessary to choose the number of switches and switch positions to fulfil this requirement. The 'recognition' of significant combinations of switch positions is carried out by motor uniselectors, and further motor uniselectors

Table I

TYPICAL ROLLING SCHEDULE FOR A PRIMARY BLOOMING MILL

Program No. 2

Pass No.	Roll Hole	Ingot Depth, in. (Side being rolled)	Ingot Width Limits, in. (Side not being rolled)	Draft, in.
		23½–25½	23½–25½	2–4
1	B	21½	24–26½	2½
2	B	19	24½–26½	2½–5
3	B	21½	19½–19½	2½
4	B	19	19½–19⅞	2½
5	B	16½	19⅞–20½	2½
6	B	14½	20½–20½	1½–2
7	A	18½	14⅞	3½
8	A	15	15½	2½
9	A	13	15½	3
10	A	10	15½	2½
11	C	13	10½	3½
12	C	9½	10½ +	½
13	C	10	10	

The arrows indicate tilting of the ingot

'translate' the data into the settings comprising the program.

The principle of translator control is best understood by taking an example of its use. As the development was made originally for a primary steel blooming mill, and as translator control has been used commercially in this field, the example taken is a 48-in. blooming mill rolling ingots of 5 or 7½ tons down to blooms having a cross-section of about 100 in².

TRANSLATOR CONTROL OF A PRIMARY BLOOMING MILL

When, in a present-day steel blooming mill, the operator has the task of rolling a particular cross-section of bloom from an ingot of a certain size, he takes all the relevant facts into account and then chooses a course of action (program). The relevant facts for a typical blooming mill would be:

(i) Initial ingot size (tons)
(ii) Finished bloom section height (in.)
(iii) Finished bloom section width (in.)
(iv) Number of passes (governed by temperature, steel quality, etc.).

The number of passes is usually an odd number because the ingot enters the mill on one side and leaves as a finished bloom on the other. The choice of the number of passes is largely based upon the experience of the operator in taking into account the required reduction, ingot temperature, and ingot shape and quality. Sometimes the final decision cannot be made until after rolling commences, as has already been explained.

Table II

PRIMARY BLOOMING MILL PROGRAMS OF SCREWDOWN SETTING FOR A SELECTION OF INPUT CONDITIONS

	Program Number							
	1	2	3	4	5	6	7	8
Input Switch Designation								
(a) Initial ingot size, tons	5	5	5	5	5	5	5	5
(b) Finished bloom size—longer side, in.	10	10	12	12	12	12	10	10
(c) Finished bloom size—shorter side, in.	10	10	10	10	9	9	8	8
(d) Number of passes	11	13	11	13	11	13	13	15
Pass number 1	21½	21½	22	22	21½	21½	21½	22½
2	19	19	19½	19	19	19½	19	20
3	21½	21½	21½	22	22	22	22	22½
4	18	19	18½	19	18	19½	19	20
5	17½	16½	17	17	17½	16½	16½	16½
6	14½	14½	14	14	14½	13	13½	13
7	15½	18½	15½	17½	14½	17½	16½	18½
8	12½	15	12½	15½	11½	15	13½	16½
9	12½	13	12½	13½	12½	13	11½	14
10	9½	10	9½	12½	10½	11½	9	12
11	10	13	12	12½	9	12½	11½	11½
12		9½		9½		10½	9½	8½
13		10		12		9	8	11½
14								9½
15								8
16								
17								

The horizontal line between two screwdown settings means 'tilt'

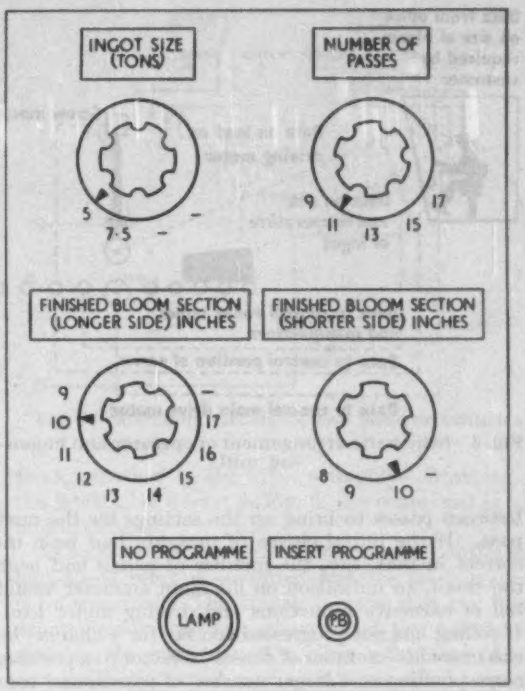

Fig. 2—Input dial-selector switches for primary blooming mill translator

The list (i) to (iv) above completely fixes a program not only of screwdown, but also of roller table main-drive motions, 'manipulator,' and 'tilt' movements. The manipulators move the ingot laterally to the appropriate part of the rolls for the pass involved. They are necessary because the rolls of a blooming mill are flanged so as to constrain the ingot and restrain spreading. A typical blooming-mill roll is shown in Fig. 1. 'Tilt' movements are carried out by tilt fingers carried by the manipulators which rotate the ingot about its main axis through 90° between appropriate passes, so as to 'square' the ingot. A typical program of integrated operation of rolling-mill movements is shown in Table I. Such programs can be correlated with the list (i) to (iv) above as shown in Table II.

It is clear that if the operator be provided with the four 'input' selector switches shown in Fig. 2 on which to set up the relevant data as listed above, the selection of the correct program becomes a problem in automatic information handling. Equipment is required to *translate* the operator's requirements into a set of data constituting a program of co-ordinated, sequenced mill movements. Figure 3 shows how the information comes to the operator in a present-day mill and how he performs a translation of the data into a pattern of co-ordinated movements. Figure 4 shows the same function carried out by a translator on the basis of the information set in by the operator.

The arrangement in Fig. 4 is for most applications quite satisfactory. The operator watches each pass, and, if all goes well, presses his 'next pass' pushbutton

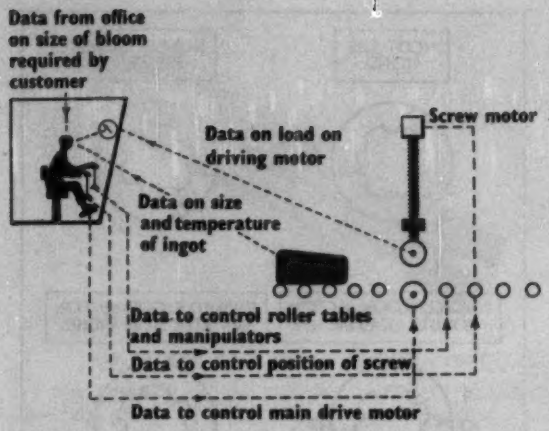
Data from office on size of bloom required by customer
Screw motor
Data on load on driving motor
Data on size and temperature of ingot
Data to control roller tables and manipulators
Data to control position of screw
Data to control main drive motor

Fig. 3—Schematic arrangement of operator and blooming mill

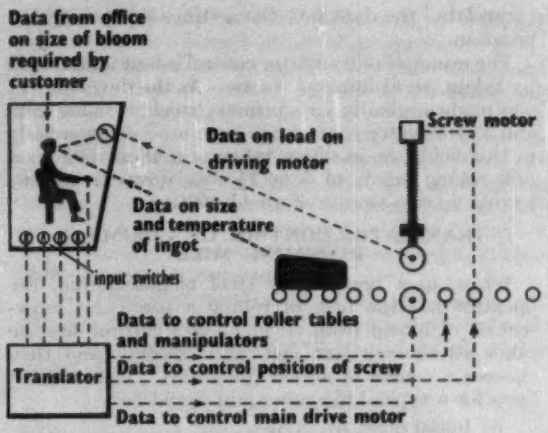
Data from office on size of bloom required by customer
Screw motor
Data on load on driving motor
Data on size and temperature of ingot
input switches
Data to control roller tables and manipulators
Translator
Data to control position of screw
Data to control main drive motor

Fig. 4—Schematic arrangement of operator, translator, and blooming mill

between passes to bring up the settings for the next pass. If the initial choice of program had been incorrect in that, say, the number of passes had been too small, an indication on his main ammeter would tell of excessive reductions and driving motor load. If rolling has not progressed too far for a change, he can move his ' number of passes ' selector to a position corresponding to a larger number of passes, and continue rolling with the correct program.

It is desirable in some mills to remove even the few routine tasks now still under manual control. The arrangement in Fig. 5 shows a scheme for a completely automatic mill, developed from Fig. 4. Although not shown in the simplified diagram, the pushbutton is now replaced by an ingot-position detecting device, and the modification of program to take account of variations of ingot temperature and hardness etc. is carried out directly by a load relay in the motor armature circuit.

THE MOTOR UNISELECTOR AND TRANSLATOR CIRCUITS

The principal function of the translator is the correlation of settings of input switches and the corresponding programs, and this is made possible in a convenient way by the use of the motor uniselector shown in Fig. 6. This is an inexpensive motor-driven rotary switch, mass-produced in Great Britain for the G.P.O. and foreign telephone companies and encountered hitherto mainly in automatic telephone exchanges.

The basic element is a row of 52 contacts arranged in a semi-circle. In a typical motor uniselector there are sixteen such rows or ' levels ' arranged side-by-side. When the uniselector motor runs, each level is swept by a wiper that engages with each of its 52 contacts or ' outlets ' in turn. Wipers may be bridging or non-bridging. The sixteen wipers, insulated from one another, are aligned with each other, usually in two sets of eight 180° apart, so that the wipers of each set always engage at the same time with corresponding contacts in each of eight levels. Such an arrangement of ' single-ended ' wipers, shown in Fig. 7, makes a 16-level 52-way switch effectively an 8-level switch with 104 positions or outlets, and it is in this form with bridging wipers that the motor uniselector is usually used in translator applications.

The great merit of the motor uniselector in translator control lies in its high speed of operation (it rotates through 200 positions in 1 s), its large number of contacts (832), and the fact that it can be stopped from full speed on any ' marked ' position. The ' marking ' of a motor-uniselector position merely involves connecting one contact of the appropriate position to positive. In its simplest form, the circuit for stopping a motor uniselector at a given outlet is shown in Fig. 8.

While the switch is running the high-speed relay is de-energized and the latch magnet energized through normally closed contacts on the high-speed relay. The latch itself can be seen in Fig. 6. It has three teeth which, while the latch magnet is energized, are held from engagement with the gear wheel of 104

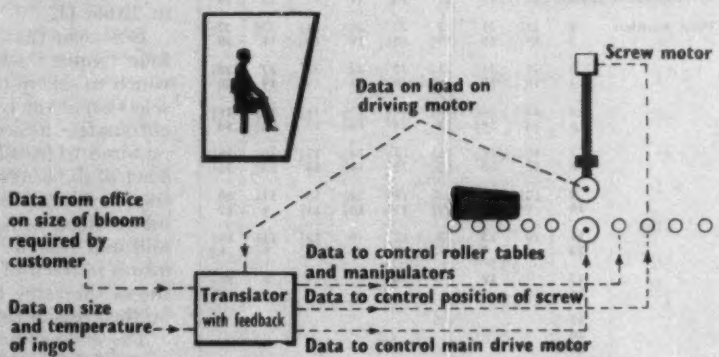
Screw motor
Data on load on driving motor
Data from office on size of bloom required by customer
Data to control roller tables and manipulators
Translator with feedback
Data to control position of screw
Data on size and temperature of ingot
Data to control main drive motor

Fig. 5—Schematic arrangement of translator and blooming mill

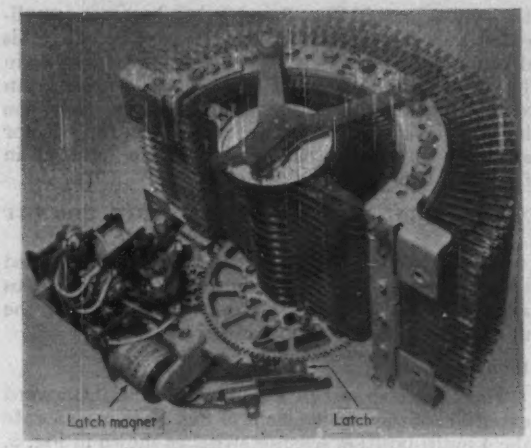

Fig. 6—The motor uniselector

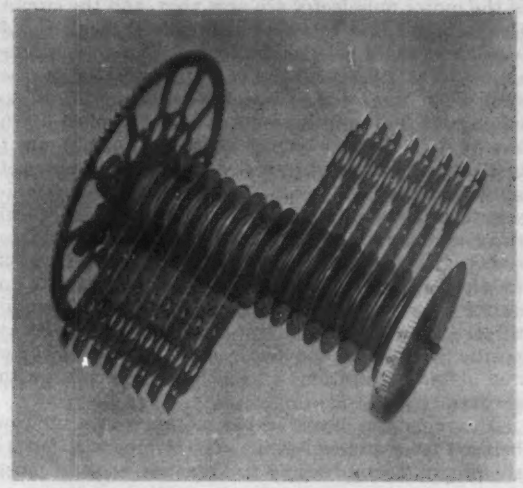

Fig. 7—Arrangement of single-ended wipers

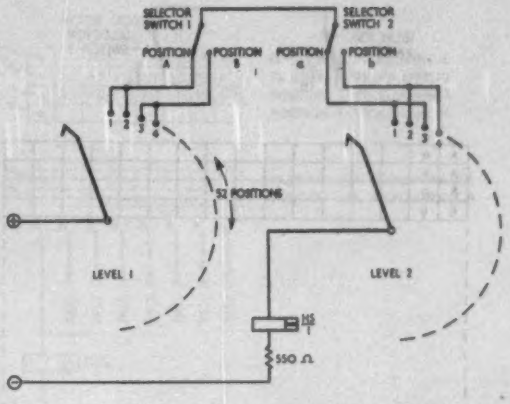

Fig. 9—Searching circuit for two selector switches

teeth, attached to the wiper assembly. Contacts on the latch, also shown in Fig. 6, are connected in the motor circuit.

As soon as the wipers reach the marked outlet the high-speed relay is energized and the latch magnet is de-energized. The timing is such that the latch drops cleanly into engagement and the uniselector stops at the marked outlet. The movement of the motor uniselector to a marked outlet is called ' searching,' and the circuit associated with the high-speed relay is called the ' searching circuit.'

Figure 9 shows a searching circuit involving two selector switches for marking the motor uniselectors on two levels. The position found by the motor uniselector now corresponds with the *combination* of selector-switch positions. Thus, if the selector switches be set to the positions *A* and *a*, the motor uniselector rotates until circuit is made from positive, through wiper 1 to selector switch 1, to selector switch 2 to wiper 2 to the high-speed relay.

A list can be made of the switch combinations and

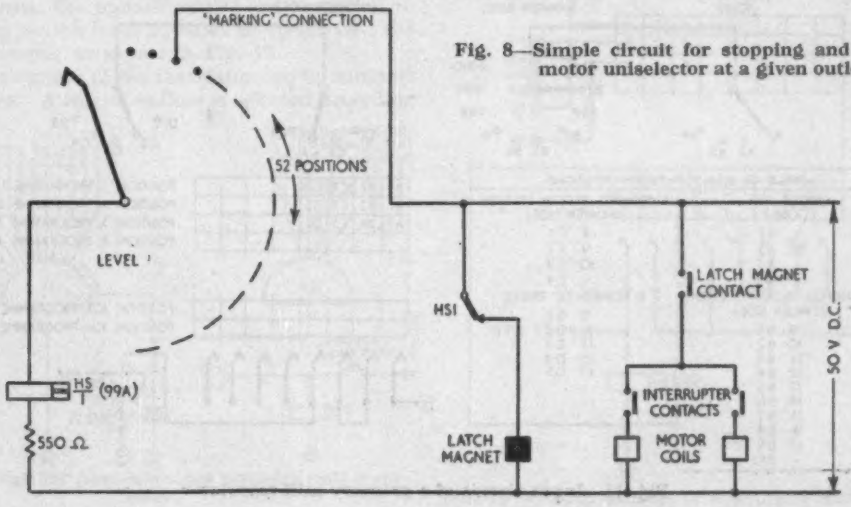

Fig. 8—Simple circuit for stopping and holding a motor uniselector at a given outlet

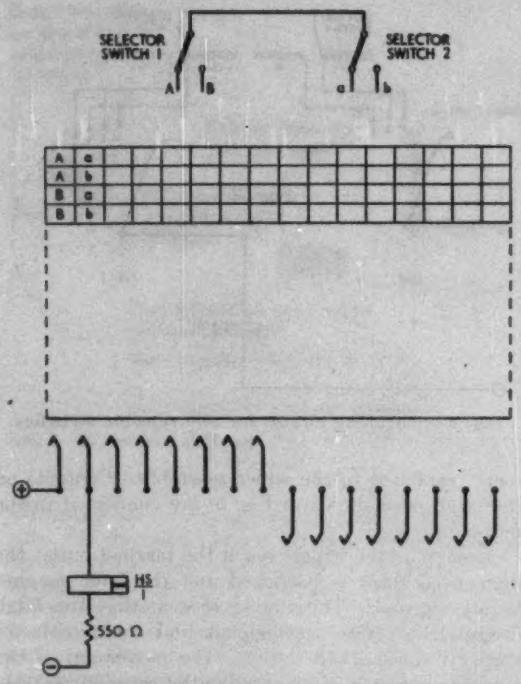

Fig. 10—Searching circuit with two selector switches (revised diagram)

the corresponding positions of the motor uniselector as follows:

Selector Switch Combination	Motor Uniselector Position
Aa	1
Ab	2
Ba	3
Bb	4

In practical circuits it is necessary to use more than two selector switches, and more than four positions of the motor uniselector. The method of representing the connections in Figs. 8 and 9 then becomes complicated and the method of Fig. 10 is adopted. This diagram shows precisely the same arrangement as in Fig. 9 but the uniselector contacts are shown as an array of squares arranged as they appear from the back of the switch, and connections from the selector switches to the motor uniselector are omitted in favour of wire reference numbers.

A PRACTICAL TRANSLATOR-CONTROL CIRCUIT FOR A PRIMARY MILL

For simplicity, the particular translator described covers screwdown control only, but no new principles are involved in larger translators for embracing all the mill auxiliaries and the main drive.

Input Section

The circuit shown in Fig. 11 is a straightforward extension of the arrangement of Fig. 10 to incorporate the 4 multi-position selector switches shown in Fig. 2, instead of the 2 two-position selectors. Four levels of the motor uniselector are now used, and the circuit to the high-speed relay now threads through the 4 levels and the 4 selector switches. The connections shown to position 1 on the motor uniselector can be seen, from the table of selector-switch positions, to correspond with a 5-ton ingot size, to be rolled down to a 10 in. × 10 in. bloom in 11 passes, i.e. program 1 in Table II. Thus, when the selector switches are set up to the positions for this program, the motor uniselector rotates until circuit is made to the high-speed relay as follows. From positive through wiper 1 to switch 1, connection A1 to switch 2, connection B2 to wiper 2, to wiper 3, to switch 3 connection C3, to switch 4 connection D2, to wiper 4, to the high-speed relay. To make this circuit the wipers must be at position 1 and thus the motor uniselector searches for and 'finds' position 1 which corresponds with program 1.

The remaining levels of the motor uniselector can be used for switching on the correct program, but as the program comprises up to 17 passes, account must

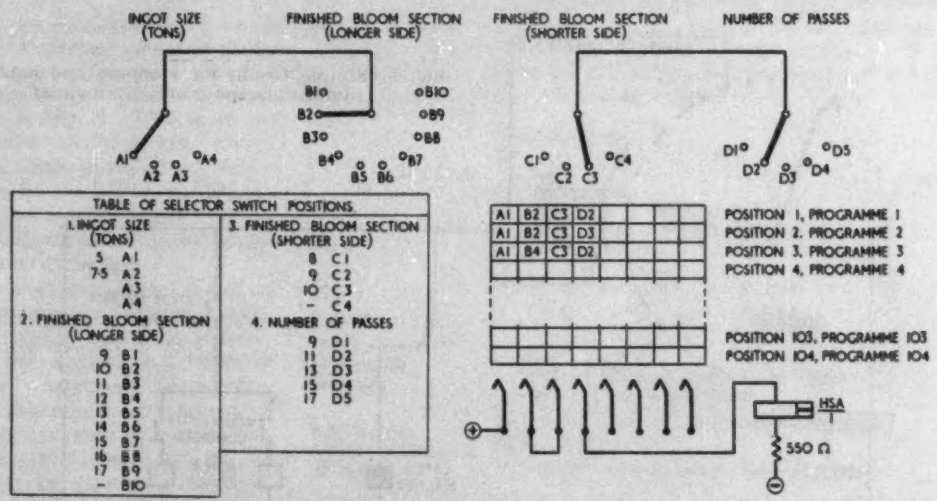

Fig. 11—Input circuit of a primary mill translator

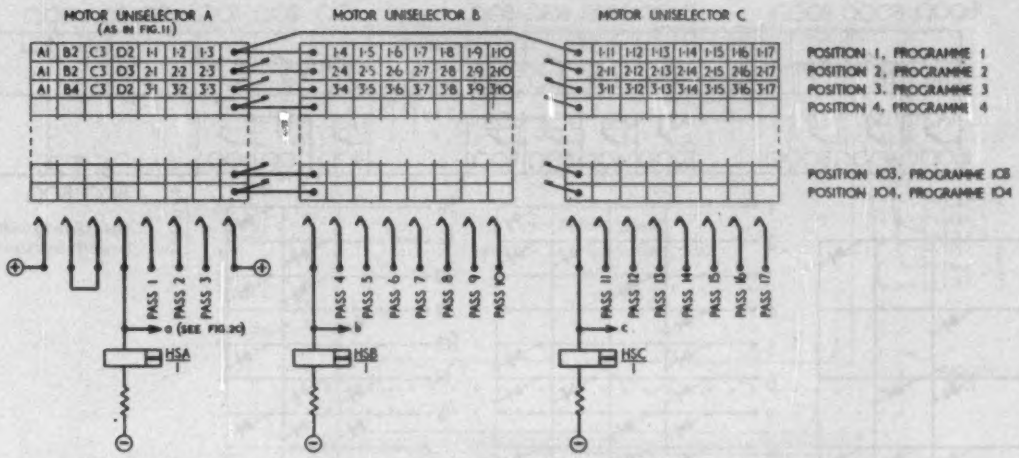

Fig. 12—Three motor uniselectors coupled in the input section of a primary mill translator

be taken of the fact that only one screwdown setting for one pass is required at one time.

Seventeen levels are therefore required for switching the correct *pass* of the correct program. The total number of 21 levels (4 for searching and 17 for the separate passes) is more than can be provided on one motor uniselector, but the problem is easily overcome by running three motor uniselectors together using the simple circuit of Fig. 12. To achieve this, the outlets of level 8 on motor uniselector *A* are connected to the corresponding outlets of level 1 of motor uniselectors *B* and *C*. The high-speed relays HSB/1 and HSC/1 can only be energized when the wipers are in line with those on motor uniselector *A* and the motor uniselectors *B* and *C* therefore rotate until their wipers are in line with those at *A*.

The 17 vacant levels are allocated to the 17 possible passes of a program. Level Z1 of a stepping switch, shown in Fig. 13, is provided to connect positive successively to the wipers of the 17 levels, by moving on one step each time the operator's 'next pass' pushbutton is pressed. If a program comprises less than 17 passes, the unused outlets are connected to the stepping switch level Z2 so as to 'pulse off' the remaining passes, as shown in Fig. 13.

The input section of the translator can be summed up as follows. A row of outlets is selected according to the program and one of the row is selected according to the pass number. Every pass of every program therefore has associated with it one outlet of the input motor uniselectors.

It remains now to be described how making an outlet alive will bring up a particular screwdown setting. This is the function of the output section of the translator.

Output Section

If 104 programs of 17 passes each are incorporated in the translator, there are 104 × 17 wires from the input section, only one of which is alive at any time. These wires, called 'correlation' wires, are given reference numbers according to the program and pass number. Thus, pass number 7 of program number 1

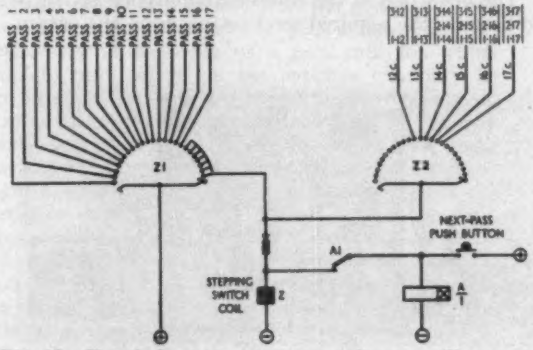

Fig. 13—Circuit for pass-sequence primary mill translator

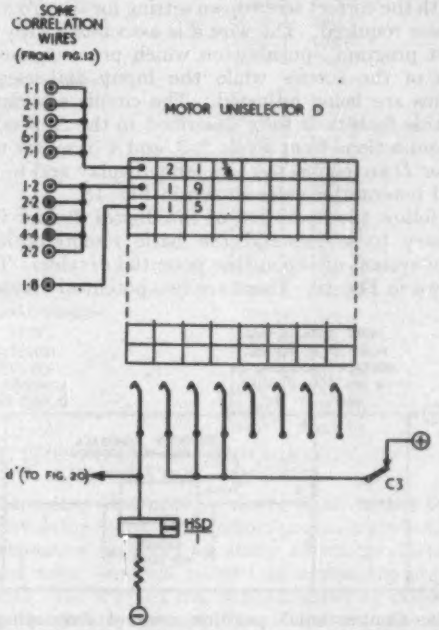

Fig. 14—Output section of a primary mill translator

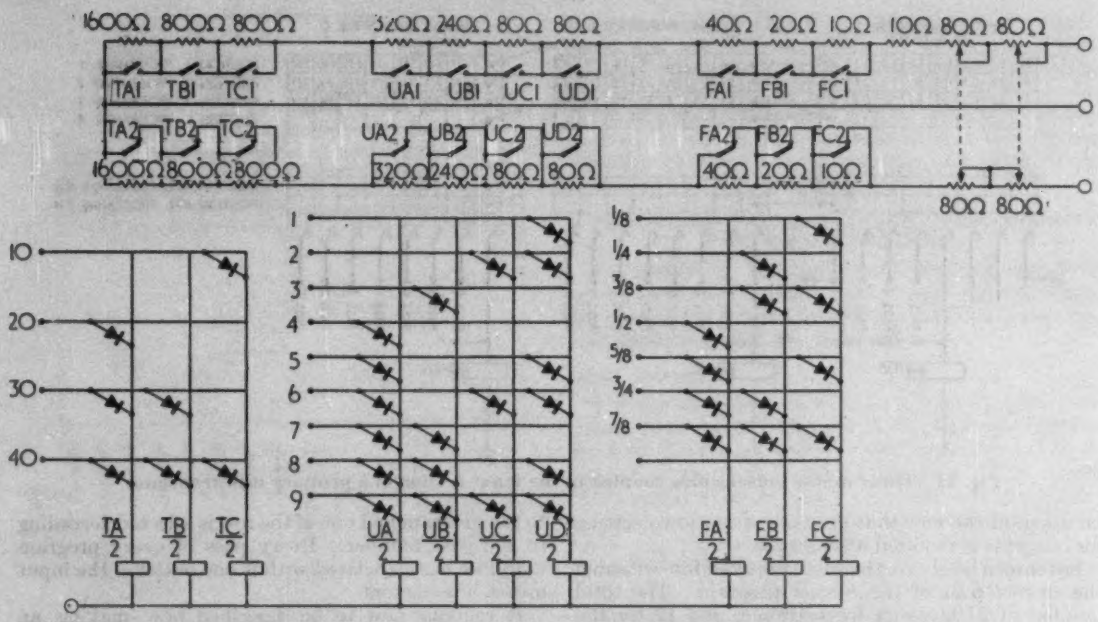

Fig. 15—Digital potential divider for operating remote position control mechanism

would be numbered 1.7. The correlation wires are connected to the outlets of a motor uniselector in the output section of the translator as shown in Fig. 14.

A position of the output motor uniselector is allocated to each required screwdown setting, and the correlation wires associated with the setting are connected to level 1 as shown in Fig. 14. The high-speed relay HSD/1 is only therefore energized when the output motor uniselector is at the position corresponding with the correct screwdown setting for the program and pass required. The wire *d* is associated with the 'insert program' pushbutton which prevents movements of the screws while the input dial-selector switches are being adjusted. The circuit associated with this feature is fully described in the Appendix. The connections from levels 2, 3, and 4 of motor uniselector *D* are connected to a lamp display and to the digital potential divider shown in Fig. 15.

To follow the operation of the digital divider it is necessary to understand the basic remote-position control system incorporating potential dividers. This is shown in Fig. 16. There are two potential dividers, one attached to the screwdown mechanism and turned through its range during the full range of screw travel, and the other manually adjusted to the desired screw position. Any difference between the actual and derived position results in a voltage XY at the amplifier which produces a signal to move the screws to a position corresponding with the desired position. In this condition the control becomes quiescent as there is no longer any voltage XY.

Reverting to Fig. 15 the digital divider is a variation of the manually-set divider, and it operates from a set of relays TA/2–FC/2. Each relay has two contacts, a normally open contact one side, and a normally closed contact the other side of the point X. The double action of make and break ensures that the total resistance of the divider does not vary. The values of resistance in the digital divider are chosen so that with different combinations of relay operation, voltages OX can be derived proportional to screwdown setting in $\frac{1}{8}$-in. steps between 0 and 50 in.

The operation of the correct combination of relays to produce the required screwsetting from the output

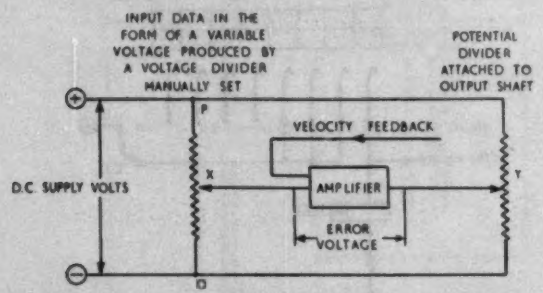

Fig. 16—Conventional position control employing a potential divider as a position-detecting element

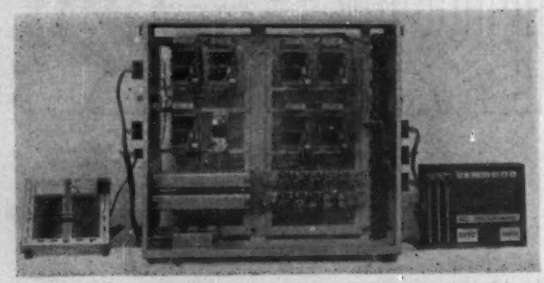

Fig. 17—Primary mill translator equipment

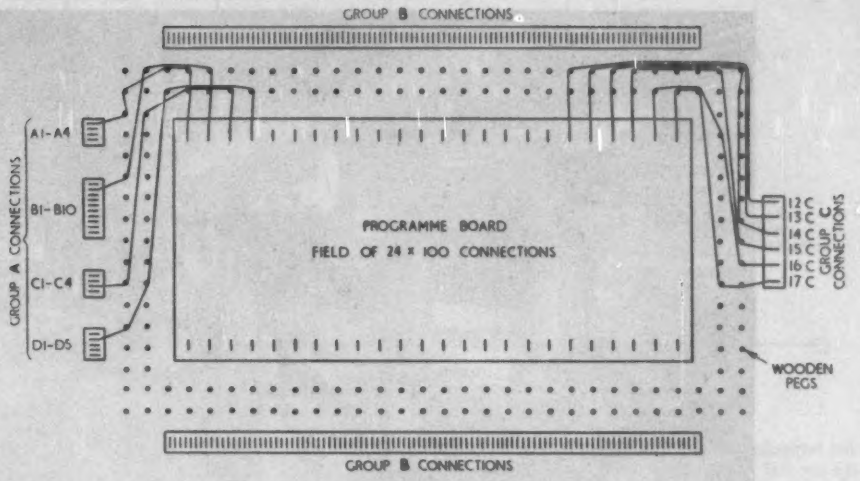

Fig. 18—Translator program board

motor uniselector signals is ensured by the use of rectifier matrices. The principle is best followed from an example.

Suppose the translator has been set up for program 1 and pass 1. The output motor uniselector rotates to position 1 and three wires 20, 1, and $\frac{3}{4}$ are made positive. These wires are shown in Fig. 15 connected to cross-wires of the three matrices. Relays TA/2, UD/2, FA/2, and FB/2 are energized. The potential divider has now resistance of 2260 Ω above X and 1740 Ω below X, and, as the total resistance is 4000 Ω and this corresponds with 50 in., the setting corresponds with 1740/4000 × 50 in. = $21\frac{3}{4}$ in.

Details of the supervisory circuit for the input and output sections of the translator are given in the Appendix.

PHYSICAL LAYOUT OF PRIMARY MILL TRANSLATOR TO FACILITATE ADDING OR CHANGING PROGRAMS

An early form of translator, in which the input switches, main cubicle, and display system are separate entities, is shown in Fig. 17. Since this prototype equipment was built considerable progress has been made.

The physical layout of a translator very much depends on the amount of information available on programs at the time of construction. If all the programs are known in advance, the equipment can be made very compact indeed. This is rare, however, particularly in the case of a new mill for which complete information on the settings can only be derived after trial and error with manual operation. In most cases, provision must be made for the easy insertion of programs on site. One method of doing this has already been developed and is illustrated diagrammatically in Fig. 18. In the middle of the translator cubicle is a large field of connections on a ' program board ' approximately 2 ft square in which each row of terminations corresponds with one program and this is surrounded by tag boards as shown. The insertion of a new program entails making one soldered connection from the tag boards marked to each solder tag in the row. The connections are routed around wooden pegs, to ensure tidy laying. For example, the connections in the group of tags marked *A* correspond with the connections A1–A4, B1–B10, C1–C4, D1–D5 in Fig. 11 and the appropriate connections are made to the first four tags of the row. The group of tags *B* corresponds with 200 settings of screwdown and connections are made from these tags to up to 17 tags (for passes 1–17 from left to right) of the row. Connections are made to the tags in group *C* when the program comprises less than 17 passes.

Thus program number 1 in Table II would be set up as follows.

If this program is the first to be inserted into the translator, the first row of tags would be used, and the following connections made:

Group *A* Connection	Program Board Connection
A1	Row 1 tag 1
B2	Row 1 tag 2
C3	Row 1 tag 3
D2	Row 1 tag 4
Group *B* Connection	
$21\frac{3}{4}$	Row 1 tag 5
19	Row 1 tag 6
$21\frac{1}{2}$	Row 1 tag 7
18	Row 1 tag 8
$17\frac{1}{4}$	Row 1 tag 9
$14\frac{1}{2}$	Row 1 tag 10
$15\frac{1}{2}$	Row 1 tag 11
$12\frac{1}{4}$	Row 1 tag 12
$12\frac{1}{4}$	Row 1 tag 13
$9\frac{3}{4}$	Row 1 tag 14
10	Row 1 tag 15
Group *C* Connection	
12C	Row 1 tag 16
13C	Row 1 tag 17
14C	Row 1 tag 18
15C	Row 1 tag 19
16C	Row 1 tag 20
17C	Row 1 tag 21

FUTURE FIELD OF APPLICATION OF TRANSLATOR CONTROL

The foregoing description shows that translator control involving motor uniselectors provides a reliable and inexpensive solution to many of the problems associated with program control of a primary steel rolling mill. The method has been accepted by important steel manufacturers and translators and are now being built commercially for this application.

Fig. 19—Typical hot-strip finishing mill Photograph by courtesy of John Summers and Sons Ltd.

The basic concept is equally and directly applicable to many other types of steel rolling mill such as slabbing and roughing mills, hot finishing, and continuous cold reduction mills, reversing cold reduction mills, Steckel mills, etc.

Plans already exist for the automatic operation of the screwdown mechanisms of hot-strip finishing mills. Such mills take in red-hot steel at about 1 in. thick, about 50 in. wide, and up to 100 ft long, and roll it in 5 or 6 mills or 'stands' at the same time, down to about 0·1 in. thick. The strip passes continuously through the stands and emerges at about 20–25 m.p.h. A typical hot-strip finishing mill is shown in Fig. 19.

The setting of the screwdown mechanisms and the speeds of the stands depend upon the thickness of metal on the input end, on the required thickness at the output end, on the quality, and on rolling temperature. Input dial-selector switches for a hot-strip finishing mill would therefore be provided for registering these quantities, and the program produced by the translator would comprise a series of concurrent screw and speed settings. The problem is a very similar one, from the viewpoint of information handling, to that of the primary mill but the screwdown settings are now concurrent on several stands instead of consecutive on a single stand.

Important as is translator control in steel rolling mills, it is by no means the only field of application. Even within the steel industry new and important applications are coming to light. The control of steel-forging operations, for example, is a suitable application, and, at present, a prototype translator is being constructed for controlling the B.I.S.R.A. forging press at Sheffield. With this translator it will be possible to set up, on the input dial-selector switches, the initial principal dimensions and shape of the ingot, and the principal dimensions and shape of the finished product, together with the grade of steel and the type of tool, and a program of tool and manipulator movements will be automatically carried out.

Non-ferrous industries engaged in rolling and other metal-working industries certainly stand to benefit as much from translator control as the steel industry and probably other industries could apply the idea to their own requirements.

LIMITATIONS OF TRANSLATOR CONTROL

There are many processes to which the translator seems at first sight to be applicable, but to which translator control with motor uniselectors would not be suitable. Generally speaking, unsuitable applications can be divided into two classes:

(i) Those which are too simple to warrant translator control

(ii) Those which are too involved for translator control to be practical.

In the first class are rolling mills rolling a very narrow range of products involving only one or two programs and in the second class are jobbing rolling mills and machine tools involving many non-repetitive machining operations whose programs are too many and too varied to be stored. The upper practical limit of program-storage capacity for translators is governed by the number of motor uniselectors involved, and by the size of the equipment if many programs have to be added or altered on site. A sensible limit in the case of a primary rolling mill would be 200 programs of up to 17 passes, i.e. 3400 different input conditions.

ADVANTAGES OF TRANSLATOR CONTROL

(1) Translator control shares with other program devices the merit of releasing the operator from routine work for duties of a more supervisory nature. This fact can be very important when, to attract reliable and intelligent personnel for important plant supervision, routine work must be reduced.

(2) The control by the operator is direct in the sense that switches are provided which are directly related to the process, the operator's knowledge of the process, and the material being processed.

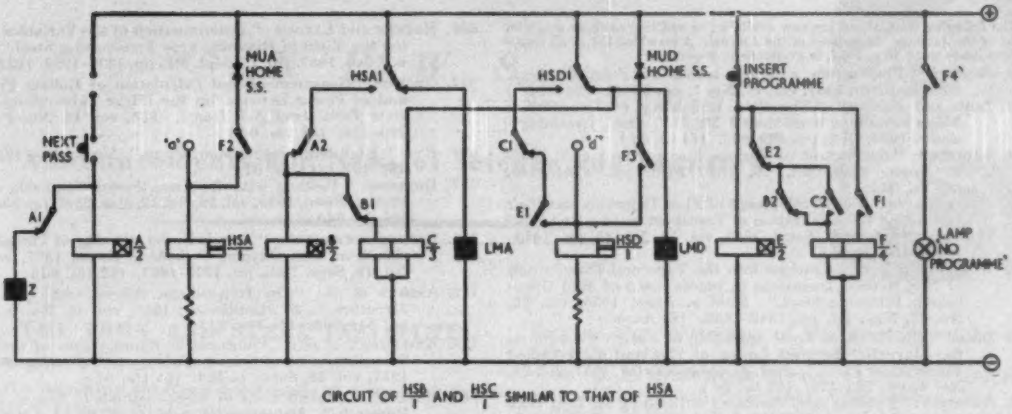

Fig. 20—Detailed supervisory circuit for motor uniselectors

(3) Translator control is self-contained. No stack of cards or rolls of tape are required.

(4) Translator control is rugged. The input switches are robust, and the rest of the equipment is standard post office equipment of proven reliability. No minute currents are carried through contacts.

(5) Translator control can be packaged. Only a few leads need be connected to the main translator cabinet and it is practical to use plugs and sockets so that a complete spare unit can be held in readiness and plugged in at a moment's notice. It opens the way to greatly simplified design and maintenance of complex electrical gear.

(6) Translator control has been fully developed and can be applied to a wide range of programming duties without redesign.

(7) Translator control with input data, comprising in part feedback signals from the controlled drive, widens the scope of practical automatic control to any degree of complexity.

(8) Translator control is cheap and simple to construct and is immediately available for application to steelworks' drives.

References

1. L. N. Bramley, G. K. Steel, and F. Seredynski: Private communication.
2. D. B. Manwaring and D. F. Nettell: Private communication.

APPENDIX

Detailed Description of the Primary Mill Translator Supervisory Circuit

Figure 20 shows the detailed circuit for the control of the high-speed motor uniselectors *A*, *B*, *C*, and *D*. The 'next pass' button and relay A/2 are the same as in Fig. 13. It will be assumed that the program has been selected and the operator is just about to press the 'next pass' button for the first pass. In this condition the motor uniselectors *A*, *B*, and *C* are at rest and therefore the contact HSA1 is closed on the left-hand contact. Contact A2 is closed at this stage and relay B/2 energized.

When the operator presses the 'next pass' button the relay A/2 becomes energized, and opens contacts A1 and A2. Contact A1 pulses the uniselector *Z* and contact A2 indirectly initiates the movement of the output motor uniselector *D* as follows. Relay B/2 becomes de-energized as soon as A2 breaks and begins to become energized again when A2 is reclosed by the operator releasing the 'next pass' button. However, as B/2 is a slugged relay the normally closed contact B1 opens some 100 ms after A2 opens. In this time relay C/4 receives a pulse which causes it momentarily to become energized. Contact C1 in the circuit of the high-speed relay HSD/1 now opens and if 'marking positive' is not on point *d* from motor uniselector *D* (*see* Fig. 14) the high-speed relay HSD/1 becomes de-energized and the motor uniselector *D* rotates to a new position corresponding with the correct screwdown setting for the next pass. Relay C/4 is held energized during the searching period by the normally closed contact HSD 1. This relay is therefore energized just before and during the movement of the output motor uniselector *D*. Contact C3 of this relay can therefore conveniently be used to disconnect wipers 2, 3, and 4 of motor uniselector *D* while the wipers are moving, and contact C4 used to inhibit the action of the remote-control mechanism during the searching period.

An 'insert program' pushbutton is mounted next to the input dial-selector switches, and until this button is pressed the effect of moving the input switches is not transmitted to the motor uniselectors. The circuit operates as follows. When the input dial-selector switches are set up for a new program, the input motor uniselectors *A*, *B*, and *C* search for the position associated with the program. In the meantime the output motor uniselector *D* is 'frozen' because the high-speed relay HSD/1 is held energized through its own contact HSD 1, and through contacts C1 and E1. As soon as the 'insert program' pushbutton is pressed, the relay E/2 becomes de-energized, contact E1 opens, and relay HSD/1 is released. Motor uniselector *D* then searches for its new position.

If either motor uniselector *A* or *D* is still rotating when the insert program pushbutton is released, then either a fault exists or no program has been built in to correspond with the setting of the input dial-selector switches.

To prevent fruitless searching, the movement of the motor uniselectors is arrested as follows. While motor uniselector *A* is rotating, relay B/2 is de-energized and contact B2 closed and while motor uniselector *D* is rotating, relay C/4 is energized, and C1 closed. After the insert program pushbutton is released the relay E/2 begins to become de-energized, but, because it is slugged, contact is made long enough through contact E2 and C1 or B2 to energize relay F/4. This relay holds itself in through contact F1. Another contact F2 makes circuit to the 'home' contacts on the motor uniselectors, and each stops rotating at its 'home' position. A lamp is also lit by relay F/4 to indicate that no program has been found by the translator.

CO-OPERATIVE TRANSLATION SERVICE

The following translations are now available, in addition to those given on p. 67 of the January, 1958, issue of the *Journal*. A classified list of all translations made since May, 1957, is available on request.

540. RUOPP: "Preparation and Utilization of Foamed Slag." *Stahl u. Eisen*, 1957, vol. 77, No. 1, pp. 36–43. (£3 5*s*. 0*d*.)

553. LIHL and ZEMSCH: "The Cold Rollability of Transformer Steels containing more than 3·3% Si." *Arch. Eisenhüttenwesen*, 1955, Oct., pp. 599–602. (£4 0*s*. 0*d*.)

554. SPITZLER: "Assessment of Various Furnace Linings." *Stahl u. Eisen*, 1956, vol. 76, Dec. 27th, pp. 1734–1740. (£3 5*s*. 0*d*.)

555. HILTERHAUS: "The Development of Flow Diagrams and their Use in the Rationalization of Transport in Iron and Steel Works." *Stahl u. Eisen*, 1955, vol. 75, No. 22, pp. 1480–1492. (£5 5*s*. 0*d*.)

558. HOFF *et al.*: "Investigations into the Type and Distribution of Non-Metallic Inclusions in Ingots made of Mild Open-hearth Rimming Steel." *Stahl u. Eisen*, 1956, vol. 76, No. 22, Nov. 1st, pp. 1442–1452. (£6 5*s*. 0*d*.)

570. LIHL: "The Effect of Final Annealing in a High Vacuum on the Magnetic Reversal Losses of Hot and Cold Rolled Transformer Plate." *Arch. Eisenhüttenwesen*, 1957, vol. 28, No. 4, pp. 223–226. (£2 0*s*. 0*d*.)

602. KHENKIN: "Feeding Steel Castings Produced by the Lost Wax Process." *Liteinoe Proizvodstvo*, 1955, No. 5, pp. 1–7. (£5 15*s*. 0*d*.)

603. SHEVAKIN *et al.*: "Improved Groove Design in the Cold Reduction of Tubes." *Stal*, 1957, May, pp. 441–444. (£2 0*s*. 0*d*.)

617. GONCHAREVSKY *et al.*: "Application of Phosphate Coatings to the Multiple Cold Drawing of Tubes." *Stal*, 1957, vol. 17, Mar., pp. 243–253. (£4 0*s*. 0*d*.)

643. WIESTER *et al.*: "Effects of Nitrogen Linkage with Aluminium on the Properties of Steels." *Stahl u. Eisen*, 1957, vol. 77, June 13th, pp. 773–784. (£5 5*s*. 0*d*.)

645. WERNER: "A New Dilatometer and its Use in Metallurgy." *Z. Metallkunde*, 1956, Jan., pp. 28–36. (£3 15*s*. 0*d*.)

647. HENDUS and WAGNER: "Study of the Behaviour of Superficial Layers by X-ray Measurements of Strain and Determination of Elastic Constants of 0·43% C Steel." *Rev. Met.*, 1955, Dec., pp. 982–994. (£3 10*s*. 0*d*.)

663. DUFLOT and RICHARD: "Notes on the Solidification and Rimming of Basic Bessemer Ingots weighing 4·6 tons." *Rev. Met.*, 1954, Sept., pp. 623–657. (£10 0*s*. 0*d*.)

667. PLOCKINGER and ROSEGGER: "Deoxidation and Technological Characteristics of Killed Basic Converter Steels. Part I—Progress of Deoxidation, Appearance and Composition of Products. Part II—Inclusions, Degree of Purity, and Mechanical and Technological Properties of Killed Basic Converter Steel." *Stahl u. Eisen*, 1957, vol. 77, May 30th, pp. 701–714; June 13th, pp. 798–804. (£9 0*s*. 0*d*.)

668. ZURCHER: "Machines for Processing Medium and Heavy Plates." *Stahl u. Eisen*, 1955, vol. 75, Sept. 8th, pp. 1182–1188. (£3 5*s*. 0*d*.)

670. ZAKHAROV *et al.*: "Smelting of Ferromanganese in Large Blast-furnaces." *Stal*, 1957, No. 7, July, pp. 580–584. (£2 0*s*. 0*d*.)

672. LEMM: "Layout of High-capacity Rolling Mills for Light Steel Sections and Wire Rod." *Stahl u. Eisen*, 1957, vol. 77, Sept. 5th, pp. 1181–1195. (£6 0*s*. 0*d*.)

674. HOLDT and GRUN: "Behaviour of Heat-resisting Steels during Creep Testing at 500–700° C: Part IV—Results of Creep Tests on Ferritic Engineering Steels." *Arch. Eisenhüttenwesen*, 1957, vol. 28, No. 5/6, May/June, pp. 269–285. (£5 5*s*. 0*d*.)

675. BUNGARDT: "Behaviour of Heat-resisting Steels during Creep Testing at 500–700° C: Part V—Results of Creep Tests on Austenitic Steels and Alloys." *Arch. Eisenhüttenwesen*, 1957, vol. 28, No. 5/6, May/June, pp. 287–304. (£5 0*s*. 0*d*.)

676. KRISCH: "Behaviour of Heat-resisting Steels during Creep Testing at 500–700° C: Part VI—Metallurgical Examinations of Austenitic and Ferritic Steels after a Long Period of Creep Stressing." *Arch. Eisenhüttenwesen*, 1957, vol. 28, No. 5/6, May/June, pp. 305–310. (£3 10*s*. 0*d*.)

677. SCHINN and RUTTMANN: "Behaviour of Heat-resisting Steels during Creep Testing at 500–700° C: Part VIII—Some Preliminary Deductions." *Arch. Eisenhüttenwesen*, 1957, vol. 28, No. 5/6, May/June, pp. 317–323. (£3 5*s*. 0*d*.)

682. BARKING and EYMANN: "Influencing the Coking Properties of Coal by Metal-Active Fillers." *Brennstoff-Chemie*, 1957, vol. 38, No. 7/8. (£4 0*s*. 0*d*.)

683. WUPPERMAN: "The Fatigue Life of Crankshafts and its Evaluation by Inspection." *Stahl. u. Eisen*, 1957, vol. 77, Aug. 22nd, p. 1117. (£2 15*s*. 0*d*.)

685. PATTERSON and OBERHOFER: "Investigation of the Refractory Lining, Blast Feed and Size of Steelworks Hot-blast Cupolas." *Gresserei*, 1957, Apr. 25th, pp. 227–237. (£5 0*s*. 0*d*.)

695. BECKER and HOFF: "Effect of Manganese and Lead Content on Non-metallic Inclusions in Free-cutting Steel." *Stahl u. Eisen*, 1957, vol. 77, Sept. 5th, pp. 1215–1220. (£2 15*s*. 0*d*.)

696. HEINEN and LATOUR: "Determination of the Variables affecting the Yield of Rimming-type Free-cutting Steel." *Stahl u. Eisen*, 1957, vol. 77, Sept. 5th, pp. 1204–1209. (£3 5*s*. 0*d*.)

697. GELEJI: "Measurement and Calculation of Rolling Pressure and of Power Demand on the Pilger Tube-rolling Mill." *Acta Tech. Acad. Sci. Hung.*, 1956, vol. 15, No. 1–2, pp. 205–218. (£2 10*s*. 0*d*.)

698. RYS: "High-temperature Microscopy." *Neue Hütte*, 1957, pp. 489–497. (£3 5*s*. 0*d*.)

707. DICKENS: "Pickling with Re-strengthened Sulphuric Acid." *Stahl u. Eisen*, 1939, vol. 59, No. 12, Mar. 23rd, pp. 364–377. (£9 0*s*. 0*d*.)

711. RELLERMEYER *et al.*: "Trends in the Refining of Phosphorus-rich Iron with Oxygen." *Stahl u. Eisen*, 1957, vol. 77, No. 19, Sept. 19th, pp. 1296–1303. (£2 15*s*. 0*d*.)

712. ASSMUS *et al.*: "On Iron–Silicon Alloys with Orientated Structure." *Z. Metallkunde*, 1957, vol. 48, No. 6, June, pp. 341–349. (£4 10*s*. 0*d*.)

713. KRISEMENT *et al.*: "Calorimetric Examination of the $\alpha \rightarrow \beta$ Transformation of Cristobalite." *Arch. Eisenhuttenwesen*, 1957, vol. 28, Sept., p. 523. (£4 15*s*. 0*d*.)

716. MALISSA: "Contributions to Micro-methods in Iron and Steel Research." *Mikrochimica Acta*, 1956, No. 1–6, pp. 474–483. (£1 10*s*. 0*d*.)

722. TYOU *et al.*: "Contribution to the Study of the Analytical Behaviour of Nitrides in Steels." *Rev. Univ. Mines*, 1956, vol. 12, Dec., pp. 641–652. (£3 5*s*. 0*d*.)

724. PERLICK: "Automation in the Iron and Steel Industry." *Neue Hütte*, 1957, Feb./Mar., pp. 92–102. (£5 10*s*. 0*d*.)

727. OBERHOFER: "The Hot-blast Cupola Furnace in Open-hearth Practice." *Stahl u. Eisen*, 1957, vol. 77, No. 10, May 16th, pp. 643–651. (£4 15*s*. 0*d*.)

738. THEUERKORN: "Change-over to Higher Specific Thermal Load in High-pressure Boiler Construction." *Brennstoff-Warme-Kraft*, 1956, Nov., pp. 521–524. (£2 5*s*. 0*d*.)

741. MEDNIKOV and KRICHEVSKY: "Electric Resistance Welding of Tubes from Cut Strip in Rimming Steel." *Stal*, 1957, Sept., pp. 819–822. (£1 5*s*. 0*d*.)

742. SMOLYAKOV *et al.*: "Contamination of Ball Bearing Steel by Refining Slag." *Stal*, 1957, Oct., pp. 893–898. (£2 10*s*. 0*d*.)

744. SEMCHENKO *et al.*: "Heating Alloy Steel Ingots in Soaking Pits." *Stal*, 1957, Oct., p. 915. (£1 5*s*. 0*d*.)

747. THUM and RICHARD: "100,000 hr. Creep Tests at 500° C on Various Types of Steel." *Arch. Eisenhüttenwesen*, 1957, vol. 28, May/June, pp. 325–337. (£5 0*s*. 0*d*.)

748. KRISCH and WEPNER: "On the Conversion of Creep Values to Other Temperatures." *Arch. Eisenhüttenwesen*, 1957, vol. 28, May/June, pp. 339–344. (£3 5*s*. 0*d*.)

760. BIRMAN: "Application of the Exothermic Mixtures and Exothermic Extensions for Heating Ingot Heads." *Stal*, 1957, No. 8, p. 718. (15*s*. 0*d*.)

771. WAKAMATSU: "Rapid Determination of Magnesium in Basic Slags." *Japan Analyst*, 1956, No. 5, pp. 264–267. (£2 15*s*. 0*d*.)

774. VOLCHEK: "Dependence of Hydraulic Activities of High-alumina Slags on their Phase Characteristics (Crystallinity and Composition)." *Doklady Akad. Nauk S.S.S.R.*, 1953, vol. 90, No. 3, pp. 437–440. (£1 0*s*. 0*d*.)

775. TOROPOV and VOLKONSKII: "Hydraulic Activity of Granulated Slags." *Doklady Akad. Nauk S.S.S.R.*, 1949, vol. 66, No. 1, pp. 95–97. (£1 0*s*. 0*d*.)

778A. BULLE: "Review of Iron and Steelmaking Practice: Part 1—Pig Iron and Steel Production." *V.D.I. Zeitschrift*, 1955, vol. 97, Nov. 1st, pp. 1111–1121. (£6 10*s*. 0*d*.)

778B. SEDLACZEK: "Review of Iron and Steelmaking Practice: Part 2—Rolling Mill Practice." *V.D.I. Zeitschrift*, 1955, vol. 97, Nov. 1st, pp. 1121–1125. (£2 15*s*. 0*d*.)

782. HÜTTEMANN: "Suitability and Selection of Blast-furnace Slag for Manufacture of Road Ballast." *Stahl u. Eisen*, 1957, vol. 77, Oct. 17th, pp. 1436–1442. (£3 10*s*. 0*d*.)

784. HARTLEIF: "Summary of the Present State of the Spectrometrical Analysis of Steel." *Stahl u. Eisen*, 1957, vol. 77, Oct. 17th, pp. 1497–1499. (£2 0*s*. 0*d*.)

790. RYABIN'KY: Development of the Iron and Steel Industry in the U.S.S.R. during 40 years of Soviet Power." *Stal*, 1957, Nov., pp. 961–964. (£2 15*s*. 0*d*.)

794. ANON.: "Ash and its Influence on Furnace and Boiler Operation." *Energie*, 1956, vol. 8, July 15th, pp. 260–264. (£3 15*s*. 0*d*.)

795. BELYAKOV: "Influence of Cold Hardening of the Edges of Cold-rolled Transformer Sheet Samples on the Electromagnetic Characteristics." *Stal*, 1957, No. 2, pp. 185–186. (£1 0*s*. 0*d*.)

798. WOLF: "Possibilities of Standardizing the Drives of Steelworks Cranes." *Stahl u. Eisen*, 1957, vol. 77, Jan. 10th, pp. 33–36. (£2 0*s*. 0*d*.)

N E W S

Announcements and News of Science and Industry

THE IRON AND STEEL INSTITUTE

Changes on Council

The following elections were made at a meeting of the Council held on 23rd January:

Vice-Presidents

Mr. E. T. Judge	Dr. C. Sykes, F.R.S.
Mr. F. H. Saniter	Mr. S. Thomson.

Members of Council

Dr. J. H. Chesters	Mr. W. F. Gilbertson
Mr. F. B. George	Dr. L. B. Pfeil, O.B.E., F.R.S.

Annual General Meeting, 1958

The Annual General Meeting is being held in London on Wednesday and Thursday, **7th and 8th May.** Full details of the programme will be announced later. The Dinner for Members is being held on the evening of Wednesday, 7th May.

Special Meeting in Belgium and Luxembourg

The Institute is holding a Special Meeting in Belgium and Luxembourg from **18th to 28th June.** The provisional programme was published in the December, 1957, issue (page 344).

NEWS OF MEMBERS

New Year Honours

Knight Bachelor

Dr. **Ashley Skelton Ward,** President of Thos. W. Ward, Ltd., and Chairman of the Park Gate Iron and Steel Co., Ltd.

M.B.E.

Miss **I. M. Slade,** Information Officer, B.I.S.R.A.

Mr. **L. W. H. Aston** has been appointed Senior Roll Representative for Armstrong Whitworth (Metal Industries) Ltd.

Dr. **D. V. Atterton** is now a member of the Board of Foundry Services International Ltd. (formerly Foundry Services (Overseas) Ltd.).

Mr. **D. J. Bell,** formerly Assistant Director of Research and Technical Development (Tubes) with Stewarts and Lloyds Ltd., is now General Manager of the Indian Steelworks Construction Company at Durgapur.

Dr. **P. E. Brookes** has left Wm. Jessop and Sons, Ltd., to join the U.K. Atomic Energy Authority, Research and Development Branch, Culcheth.

Mr. **D. C. Brown** has left C. A. Parsons and Co., Ltd., to rejoin Rotol Ltd.

Mr. **A. Chamberlain** has joined the U.K. Atomic Energy Authority at the Industrial Group Headquarters, Risley, as an Engineer I.

Mr. **Lewis Chapman** has been appointed Deputy Chairman of the Birmingham Small Arms Company Ltd.

Mr. **D. R. G. Davies** has been appointed Technical Services Superintendent of the Workington Iron and Steel Company.

Mr. **O. F. Grazebrook** has retired from the Chairmanship of The British Rollmakers Corporation Ltd.

Mr. **E. J. Hancock** has terminated his appointment as Superintendent of Blast Furnaces at the Tata Iron and Steel Co., Ltd., Jamshedpur.

Mr. **N. C. Lake** has been appointed a Director and Deputy Managing Director of Head Wrightson and Co., Ltd.

Mr. **H. B. Lloyd** has left the Workington Iron and Steel Company.

Sir **Andrew McCance** has been elected to the Board of Harland and Wolff Ltd., in place of the late Sir John Craig.

Mr. **T. Roberts** has retired from the position of Chief Metallurgist to the Brymbo Steel Co., Ltd., after 55½ years' service.

Dr. **P. Samuel** has accepted an appointment as one of Her Majesty's Inspectors; he is working in the Midlands Division of the Ministry of Education, and will be advising nationally on metallurgy.

Mr. **T. G. Seatter** has joined the Guest, Keen Iron and Steel Co., Ltd., as Head of the Mechanical and Electrical Plant Purchasing Section.

Mr. **S. P. Thompson** has left British Insulated Callender's Cables Ltd. to join Standard Telephones and Cables Ltd.

Mr. **P. C. Thornton** is now Lecturer in Metallurgy at the College of Technology, Ashley Down, Bristol.

Mr. **W. T. Vizer-Harmer** has been appointed Commercial Director of Steel, Peech and Tozer.

Obituary

Mr. **James Alfred Bond** (*Williams Prizeman; elected* 1936), of Scunthorpe, on 9th December, 1957.

Mr. **William Walter Franklin** (*elected* 1936), of Ashford-in-the-Water, Derbyshire, on 18th December, 1957.

Mr. **William Broke Hoppner Gallwey** (*elected* 1949) of Sheffield, on 14th December, 1957.

Mr. **Alastair McLeod** (*elected* 1937), of London, on 3rd January, 1958.

Mr. **Thomas Francis Russell** (*elected* 1919), of Sheffield, on 4th December, 1957.

IRON AND STEEL ENGINEERS GROUP

Thirty-sixth Meeting

The Thirty-Sixth Meeting of the Iron and Steel Engineers Group will be held at the offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on Wednesday and Thursday, **16th and 17th April, 1958,** from 10 A.M. to 4 P.M. on each day.

The first day will be devoted to the discussion of a paper on "Modern Development of the Ward Leonard Principle and Applications in Steel Works," by C. A. Dodd, in the morning and to a general discussion of "Electrical Maintenance in Iron and Steel Works" in the afternoon.

The second day will be devoted to the discussion of papers on "The Application of Remote Position Control to Screwdown Drives of Rolling Mills" by L. N. Bramley, G. K. Steel, and F. Seredynski, and "The Application of Remote Position Control to Forging" by F. Seredynski, G. K. Steel and others, in the morning, and "Translator Control" by W. N. Jenkins in the afternoon.

CONTRIBUTORS TO THE JOURNAL

F. J. Armson, M.SC., A.R.I.C.—Head of Applied Chemistry Section, G.K.N. Group Research Laboratory.

Mr. Armson was educated at Hinckley Grammar School and Loughborough College of Technology. Following research at Loughborough on chromatography, he was awarded an external London M.Sc. degree. He joined the Chemical Inspectorate (Ministry of Supply) in 1947 as a Scientific Officer, working mainly on analytical research and development in connection with the atomic energy programme. In 1952 he became a member of the G.K.N. Group Research Laboratory, where he is now Head of the Applied Chemistry Section. He has been concerned principally with the determination of non-metallic compounds in steel and with various works process studies, especially in connection with electrical sheet production.

H. L. Bennett—Member of Applied Chemistry Section, G.K.N. Group Research Laboratory.

Mr. Bennett was educated at the Dudley and Staffordshire Technical College and later at the Wolverhampton and Staffordshire College of Technology. He then joined the Manor Works laboratory of Joseph Sankey and Sons Ltd. as a junior analytical chemist. After National Service in the R.A.F., he joined his present company in 1948; his work there has been concerned chiefly with silicon iron. Mr. Bennett is a Graduate of the Royal Institute of Chemistry.

S. Velken—Head of Control Department, Elektrokemisk A/S, Fiskaa Verk, Kristiansand S., Norway.

Sigurd Velken was educated at the Technical University of Norway, Trondheim. In 1940 he joined the laboratory staff of Elektrokemisk A/S, Fiskaa Verk, and became Chief Chemist of Stavanger Electro-Staalverk A/S in 1949. He was granted a Research Scholarship by the Royal Norwegian Council for Scientific and Industrial Research in 1951, and studied analytical instrumental methods for a year at different laboratories in the U.K. For two years he was a research chemist with SINTEF (The Engineering Research Foundation at the Technical University of Norway); Mr. Velken took up his present position in 1956.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Conference on Computers

The Operational Research Department is organizing a one-day conference on the use of digital computers in the iron and steel industry, to be held in London on Tuesday, 15th April, 1958. Papers will be presented for discussion by users in the steel industry on their experiences of using computers for calculating pay-roll, for studying works operations, on conducting feasibility studies, and on training staff to operate computers.

The B.I.S.R.A. Pegasus computer will be demonstrated to interested members of the Conference on Monday afternoon, 14th April, and Wednesday morning, 16th April, 1958. Further details may be obtained from the Technical Secretary, Operational Research Department, B.I.S.R.A., 140 Battersea Park Road, London, S.W.11.

NEWS OF SCIENCE AND INDUSTRY

Computation and Automatic Control

The rapid growth of automation has led some twenty societies having interests in the fields of computation, process control, and data processing to set up a central organization to provide more effective liaison between the interested bodies, to be known as the British Conference on Automation and Computation. This will consist of three groups:

A. The British Group for the Engineering Applications of Automation
B. The British Group for Computation and Automatic Control
C. The British Group for the Sociological and Economic Aspects of Automation Techniques.

Group *B* was formally constituted at a meeting on 20th December, 1957; The Iron and Steel Institute is one of the member Societies. The objects of the group are to foster the development and applications of automatic controls, computing and data processing equipment, and programming techniques; to afford a common meeting ground for the member organizations whereby such of their activities coming within the scope of the group may be co-ordinated and extended; to maintain liaison with other groups of the Conference; to encourage and co-ordinate the presentation at international conferences of British papers on subjects within the scope of the group; and to maintain contact with corresponding groups in other countries.

Mr. T. E. Goldup (President of the Institution of Electrical Engineers) is Chairman of the Group; secretarial services are being provided by that institution.

New Mill at Attercliffe

The Lord Mayor of Sheffield, Ald. A. Ballard, C.B.E., opened the new 10½-in. double-duo bar mill at the Attercliffe steelworks of Sanderson Brothers and Newbould Ltd., on 20th December, 1957. The new mill, which was built by The Brightside Foundry and Engineering Co., Ltd., replaces two existing mills. It will handle a mixed rolling programme of high-speed, tool, and alloy steels, including steels for bright turning.

U.S. Army Support for Metallurgical Research

Research in American Universities, research institutes, and industrial laboratories has been assisted for some years by the United States Government through its military services. The programme administered by the U.S. Army has now been extended to Western Europe; the European Research Office of the United States Army Research and Development Liaison Group has been set up at Rheingau Allee 2, Frankfurt-am-Main, Germany.

This organization invites proposals for research, arranges suitable contracts, and assists in their execution. Research projects likely to receive support cover a wide range of the basic sciences; among the subjects dealt with by the Material Sciences Branch of the Group are metallurgy, refractories, ceramics, packaging, and handling. There is no restriction on the publication of results, and patent rights are reserved to the originator, although free licence must be given to the U.S. Army for use on government requirements.

Further information may be obtained from the address given above.

Induction Furnace at Jessops

A 600-lb vacuum induction furnace is to be installed at the Sheffield works of William Jessop and Sons, Ltd., as part of the company's expansion scheme. The new furnace, which is being built in the U.K. by Wild-Barfield Electric Furnaces Ltd. to the design of the NRC Equipment Company of Boston, Mass., includes such features as a stainless-steel vacuum tank, co-axial power feed-through for the h.f. current, and a special bulk charging and alloying lock to enable additions to be made to the melt without breaking the main tank vacuum.

Iron and Steel Plant for Rhodesia

A 16-ft dia. blast-furnace forms part of the expansion programme of the Rhodesian Iron and Steel Company (Pvt.) Ltd. for its works near Que-Que, Southern Rhodesia. This furnace, which will have fully automatic weighing, charging, and bell-operating controls, is being supplied by Head, Wrightson and Co., S.A. (Pty.) Ltd., who are also installing a 3,000,000 ft³/h gas cleaning plant for treatment of the gas produced by the new furnace and the two smaller existing furnaces.

New Nucleonic Thickness Gauge

A new A.G.C. (automatic gauge control) nucleonic thickness gauge, designed for use on cold strip mills rolling brass, copper, and steel, has been produced by the Baldwin Instrument Co., Ltd. It employs the *bremsstrahlung* radiation produced by a beta-emitting radioactive source, strontium 90. Whereas with beta radiation the maximum thickness of steel measurable is about 0·020 in., with *bremsstrahlung* a range of about 0·004–0·400 in. can be covered.

Radiation from the source holder is directed at a detector with the moving metal strip passing in between. The radiation in passing through the metal is weakened by an amount depending on the strip thickness. The detector and its associated amplifier measure the intensity of radiation penetrating the strip and express it in units of thickness. This in turn is converted into a reading in terms of deviation from a preset specified thickness.

When deviation exceeds a certain preset thickness in either a positive or negative direction, a discriminator causes relays to operate which in turn cause the screw-down motors to operate. The control action has two discrete functions, one to apply small intermittent corrections to the screw-down when the material exceeds tolerance by a small amount and one to apply a radical and continuous correction when tolerance is exceeded by a larger amount.

As metal rolling is an intrinsically intermittent process, there are regular intervals during which no strip is passing through the mill. This instrument makes use of such intervals to carry out automatic standardization. As the tail end of a strip passes through the mill, the measuring head is withdrawn and the instrument checks itself against a standard sample which is automatically inserted into the measuring gap. If the equipment is out of adjustment, a servo system automatically applies a correction, thereby ensuring that the instrument is at all times operating correctly.

The first A.G.C. thickness gauge has been installed on a W. H. A. Robertson 4-high rolling mill at the works of D. F. Taylor and Co., Ltd. On this mill, the strip thickness of brass being rolled is 0·030–0·007 in. on the ingoing side and the normal finished gauge is 0·005 in. The measuring head is sited between the nip and the reeler and feeds the main electronic console which is sited remote from the mill. The minimum stable automatic control tolerance is ± 0·00015 in. and the normal working tolerance in this particular installation is ± 0·0003 in.

Coal Preparation for Coking

Woodall-Duckham Construction Co., Ltd., has been granted an exclusive licence to build plants in Great Britain in accordance with the Burstlein process of coal preparation for coking dependent upon selective and petrographic treatment. This process was developed by M. Eugène Burstlein at the Thionville plant of the Société Lorraine-Escaut, where it has been in regular use for the last six years, and on the basis of experience with numerous Continental installations the process can now be regarded as fully established.

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The second day will be devoted to the discussion of papers on "The Application of Remote Position Control to Screwdown Drives of Rolling Mills" by L. N. Bramley, G. K. Steel, and F. Seredynski, and "The Application of Remote Position Control to Forging" by F. Seredynski, G. K. Steel and others, in the morning, and "Translator Control" by W. N. Jenkins in the afternoon.

CONTRIBUTORS TO THE JOURNAL

F. J. Armson, M.SC., A.R.I.C.—Head of Applied Chemistry Section, G.K.N. Group Research Laboratory.

Mr. Armson was educated at Hinckley Grammar School and Loughborough College of Technology. Following research at Loughborough on chromatography, he was awarded an external London M.Sc. degree. He joined the Chemical Inspectorate (Ministry of Supply) in 1947 as a Scientific Officer, working mainly on analytical research and development in connection with the atomic energy programme. In 1952 he became a member of the G.K.N. Group Research Laboratory, where he is now Head of the Applied Chemistry Section. He has been concerned principally with the determination of non-metallic compounds in steel and with various works process studies, especially in connection with electrical sheet production.

H. L. Bennett—Member of Applied Chemistry Section, G.K.N. Group Research Laboratory.

Mr. Bennett was educated at the Dudley and Staffordshire Technical College and later at the Wolverhampton and Staffordshire College of Technology. He then joined the Manor Works laboratory of Joseph Sankey and Sons Ltd. as a junior analytical chemist. After National Service in the R.A.F., he joined his present company in 1948; his work there has been concerned chiefly with silicon iron. Mr. Bennett is a Graduate of the Royal Institute of Chemistry.

S. Velken—Head of Control Department, Elektrokemisk A/S, Fiskaa Verk, Kristiansand S., Norway.

Sigurd Velken was educated at the Technical University of Norway, Trondheim. In 1940 he joined the laboratory staff of Elektrokemisk A/S, Fiskaa Verk, and became Chief Chemist of Stavanger Electro-Staalverk A/S in 1949. He was granted a Research Scholarship by the Royal Norwegian Council for Scientific and Industrial Research in 1951, and studied analytical instrumental methods for a year at different laboratories in the U.K. For two years he was a research chemist with SINTEF (The Engineering Research Foundation at the Technical University of Norway); Mr. Velken took up his present position in 1956.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Conference on Computers

The Operational Research Department is organizing a one-day conference on the use of digital computers in the iron and steel industry, to be held in London on Tuesday, 15th April, 1958. Papers will be presented for discussion by users in the steel industry on their experiences of using computers for calculating pay-roll, for studying works operations, on conducting feasibility studies, and on training staff to operate computers.

The B.I.S.R.A. Pegasus computer will be demonstrated to interested members of the Conference on Monday afternoon, 14th April, and Wednesday morning, 16th April, 1958. Further details may be obtained from the Technical Secretary, Operational Research Department, B.I.S.R.A., 140 Battersea Park Road, London, S.W.11.

NEWS OF SCIENCE AND INDUSTRY

Computation and Automatic Control

The rapid growth of automation has led some twenty societies having interests in the fields of computation, process control, and data processing to set up a central organization to provide more effective liaison between the interested bodies, to be known as the British Conference on Automation and Computation. This will consist of three groups:

A. The British Group for the Engineering Applications of Automation
B. The British Group for Computation and Automatic Control
C. The British Group for the Sociological and Economic Aspects of Automation Techniques.

Group *B* was formally constituted at a meeting on 20th December, 1957; The Iron and Steel Institute is one of the member Societies. The objects of the group are to foster the development and applications of automatic controls, computing and data processing equipment, and programming techniques; to afford a common meeting ground for the member organizations whereby such of their activities coming within the scope of the group may be co-ordinated and extended; to maintain liaison with other groups of the Conference; to encourage and co-ordinate the presentation at international conferences of British papers on subjects within the scope of the group; and to maintain contact with corresponding groups in other countries.

Mr. T. E. Goldup (President of the Institution of Electrical Engineers) is Chairman of the Group; secretarial services are being provided by that institution.

New Mill at Attercliffe

The Lord Mayor of Sheffield, Ald. A. Ballard, C.B.E., opened the new 10¼-in. double-duo bar mill at the Attercliffe steelworks of Sanderson Brothers and Newbould Ltd., on 20th December, 1957. The new mill, which was built by The Brightside Foundry and Engineering Co., Ltd., replaces two existing mills. It will handle a mixed rolling programme of high-speed, tool, and alloy steels, including steels for bright turning.

U.S. Army Support for Metallurgical Research

Research in American Universities, research institutes, and industrial laboratories has been assisted for some years by the United States Government through its military services. The programme administered by the U.S. Army has now been extended to Western Europe; the European Research Office of the United States Army Research and Development Liaison Group has been set up at Rheingau Allee 2, Frankfurt-am-Main, Germany.

This organization invites proposals for research, arranges suitable contracts, and assists in their execution. Research projects likely to receive support cover a wide range of the basic sciences; among the subjects dealt with by the Material Sciences Branch of the Group are metallurgy, refractories, ceramics, packaging, and handling. There is no restriction on the publication of results, and patent rights are reserved to the originator, although free licence must be given to the U.S. Army for use on government requirements.

Further information may be obtained from the address given above.

Induction Furnace at Jessops

A 600-lb vacuum induction furnace is to be installed at the Sheffield works of William Jessop and Sons, Ltd., as part of the company's expansion scheme. The new furnace, which is being built in the U.K. by Wild-Barfield Electric Furnaces Ltd. to the design of the NRC Equipment Company of Boston, Mass., includes such features as a stainless-steel vacuum tank, co-axial power feed-through for the h.f. current, and a special bulk charging and alloying lock to enable additions to be made to the melt without breaking the main tank vacuum.

Iron and Steel Plant for Rhodesia

A 16-ft dia. blast-furnace forms part of the expansion programme of the Rhodesian Iron and Steel Company (Pvt.) Ltd. for its works near Que-Que, Southern Rhodesia. This furnace, which will have fully automatic weighing, charging, and bell-operating controls, is being supplied by Head, Wrightson and Co., S.A. (Pty.) Ltd., who are also installing a 3,000,000 ft³/h gas cleaning plant for treatment of the gas produced by the new furnace and the two smaller existing furnaces.

New Nucleonic Thickness Gauge

A new A.G.C. (automatic gauge control) nucleonic thickness gauge, designed for use on cold strip mills rolling brass, copper, and steel, has been produced by the Baldwin Instrument Co., Ltd. It employs the *bremsstrahlung* radiation produced by a beta-emitting radioactive source, strontium 90. Whereas with beta radiation the maximum thickness of steel measurable is about 0·020 in., with *bremsstrahlung* a range of about 0·004–0·400 in. can be covered.

Radiation from the source holder is directed at a detector with the moving metal strip passing in between. The radiation in passing through the metal is weakened by an amount depending on the strip thickness. The detector and its associated amplifier measure the intensity of radiation penetrating the strip and express it in units of thickness. This in turn is converted into a reading in terms of deviation from a preset specified thickness.

When deviation exceeds a certain preset thickness in either a positive or negative direction, a discriminator causes relays to operate which in turn cause the screw-down motors to operate. The control action has two discrete functions, one to apply small intermittent corrections to the screw-down when the material exceeds tolerance by a small amount and one to apply a radical and continuous correction when tolerance is exceeded by a larger amount.

As metal rolling is an intrinsically intermittent process, there are regular intervals during which no strip is passing through the mill. This instrument makes use of such intervals to carry out automatic standardization. As the tail end of a strip passes through the mill, the measuring head is withdrawn and the instrument checks itself against a standard sample which is automatically inserted into the measuring gap. If the equipment is out of adjustment, a servo system automatically applies a correction, thereby ensuring that the instrument is at all times operating correctly.

The first A.G.C. thickness gauge has been installed on a W. H. A. Robertson 4-high rolling mill at the works of D. F. Taylor and Co., Ltd. On this mill, the strip thickness of brass being rolled is 0·030–0·007 in. on the ingoing side and the normal finished gauge is 0·005 in. The measuring head is sited between the nip and the reeler and feeds the main electronic console which is sited remote from the mill. The minimum stable automatic control tolerance is ± 0·00015 in. and the normal working tolerance in this particular installation is ± 0·0003 in.

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Bibliography on Adhesive Bonding of Metals

This is a selected list of over 150 annotated references to books and magazine articles published from 1947 to 1957, covering all aspects of adhesive *metal-to-metal* bonding, including references to theory, technology, properties, and methods of application. In addition to application in the aircraft industry, the references deal with many other products such as tools, machinery parts, electrical apparatus and wiring, pistons, metal window frames, furniture, bicycles, etc.

This "ESL Bibliography No. 12" may be obtained from the Engineering Societies Library, 29 West 39th Street, New York 18, N.Y., U.S.A., price $2.00.

Industrial Publications Received

A new leaflet on high-speed steels has been received from Darwins Ltd., Fitzwilliam Works, Sheffield.

"A Comprehensive Dust Collection and Control Service" is described in Publication No. 72 of W. C. Holmes and Co., Ltd., Huddersfield.

Publication No. 69 "Holmes-Elex Electrical Precipitators" has recently been issued by W. C. Holmes and Co., Ltd., Turnbridge, Huddersfield.

The London and Scandinavian Metallurgical Co., Ltd., has published a 48-page illustrated book entitled "High Speed Tungsten Alloy—A Melting Base."

The latest leaflet (No. V51) from the Incandescent Heat Company Ltd., deals with the "Incandescent-Laclede Interchangeable Suspended Arch."

Two recent leaflets are available from Hadfields Ltd., entitled "The New Hecla Pneumatic Tub Retarder" and "Cut Your Machining Costs by Using Precision Castings."

A wide range of alloys for foundry use is described in publication No. 165 "Use 'em—Bemco Briquetted and Graded Alloys," from Union Carbide Ltd.

A waterless wash-station for operatives is the subject of a leaflet from Deb Chemical Proprietaries Ltd.

DIARY

3rd Feb.—Cleveland Institution of Engineers—"Iron Ore from the North (Labrador)," by J. M. Purse (*film*)—Cleveland Scientific and Technical Institution, Middlesbrough, 6.30 p.m.

3rd Feb.—Institute of British Foundrymen (Sheffield and District Branch)—"The Application of the CO_2 Moulding Process," by T. C. Wilson—Sheffield College of Commerce and Technology, Pond Street, Sheffield, 7 p.m.

4th Feb.—Institute of Metals (Oxford Local Section)—"Technical Control of Some Metalworking Processes," by Professor A. R. E. Singer—Cadena Café, Cornmarket Street, Oxford, 7 p.m.

4th Feb.—Institute of Metals (South Wales Local Section)—"Secondary Metal Recovery," by H. J. Miller—Department of Metallurgy, University College, Swansea, 6.30 p.m.

4th Feb.—Sheffield Metallurgical Association—"Vacuum Spectroscopy," by K. M. Bills—B.I.S.R.A., Hoyle Street, Sheffield, 7 p.m.

5th–7th Feb.—Symposium on Recent Developments in Foundry Technology—National Metallurgical Laboratory, Jamshedpur, India.

6th Feb.—Institute of Metals (Birmingham Local Section)—"Porous and Infiltrated Metals," by J. E. Elliott—College of Technology, Gosta Green, Birmingham, 6.30 p.m.

6th Feb.—Institute of Metals (London Local Section)—"Corrosion by Liquid Metals," by Dr. B. R. T. Frost—17 Belgrave Square, London, S.W.1, 6.30 p.m.

6th Feb.—Leeds Metallurgical Society—"The Russian Steel Industry," by R. Wilcock—Chemistry Wing, The University, Leeds, 7.15 p.m.

8th Feb.—Swansea and District Metallurgical Society—"The Production of Alloy Steels," by F. T. Bagnall—Central Library, Swansea, 6.30 p.m.

10th Feb.—East Midlands Metallurgical Society—Members' Night—Nottingham and District Technical College, Shakespeare Street, Nottingham, 7.30 p.m.

10th Feb.—Institute of Metals (Scottish Local Section)—"Recent Developments in the Foundry," by Dr. D. V. Atterton—39 Elmbank Crescent, Glasgow, C.2, 6.30 p.m.

10th Feb.—Institution of Production Engineers (Sheffield Section)—"Automation in the Steel Industry," by Dr. R. H. Baulk—Grand Hotel, Sheffield, 6.30 p.m.

10th Feb.—Lincolnshire Iron and Steel Institute—"Generation of Nuclear Power, with Particular Reference to the Steel Industry," by R. D. Vaughan—North Lindsey Technical College, Scunthorpe, 7.30 p.m.

11th Feb.—Institution of Engineers and Shipbuilders in Scotland—"Welded Ship Construction—Records of Common Fractures and Their Causes," by H. R. Gibbs and J. M. Boyd—39 Elmbank Crescent, Glasgow.

11th Feb.—Newport and District Metallurgical Society—Industrial films—Whitehead Institute, Cardiff Road, Newport, 7 p.m.

11th Feb.—Sheffield Metallurgical Association—"Developments in the Use of Refractories at the Steel Division of the Steel Company of Wales Ltd.," by G. M. Wakeman—B.I.S.R.A., Hoyle Street, Sheffield, 7 p.m.

12th Feb.—Manchester Metallurgical Society—"Plastics versus Metals," by J. M. J. Estevez—Central Library, Manchester, 6.30 p.m.

12th Feb.—North Wales Metallurgical Society—"Developments in Ironmaking Plants and Practice," by G. D. Elliot, O.B.E.—Flintshire Technical College, Connah's Quay, near Chester, 7.15 p.m.

14th Feb.—West of Scotland Iron and Steel Institute—"High-temperature Testing," by J. Glen—39 Elmbank Crescent, Glasgow, 6.45 p.m.

17th Feb.—Sheffield Metallurgical Association and Sheffield Society of Engineers and Metallurgists—"Low Carbon Bainitic Steels," by Dr. K. J. Irvine—Engineering Lecture Theatre, The University, St. George's Square, Sheffield, 7.30 p.m.

18th Feb.—North East Metallurgical Society—"Modern Development in Iron and Steelworks Refractories," by H. M. Richardson—Cleveland Scientific and Technical Institution, Middlesbrough, 7.15 p.m.

18th Feb.—Sheffield Metallurgical Association—"Penetrant Methods of Inspection," by Dr. R. Schnurmann—B.I.S.R.A., Hoyle Street, Sheffield, 7 p.m.

20th Feb.—Ebbw Vale Metallurgical Society—"Hydraulic Drive—The Modern Transmission," by R. H. Fett (Joint meeting with the Engineers Group of The Iron and Steel Institute)—Richard Thomas and Baldwins Lecture Room, 7.15 p.m.

20th Feb.—Institute of Metals (Birmingham Local Section)—"Neutron Irradiation Effects in Metals," by Professor J. G. Ball—Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham, 6.30 p.m.

20th Feb.—Staffordshire Iron and Steel Institute—"The Impact of High-speed Weapons on Materials of Construction," by F. Radcliffe—Station Hotel, Dudley, 7.30 p.m.

25th Feb.—Sheffield Metallurgical Association—"Metallurgical Requirements of the Aircraft Industry in Present Conditions," by G. Meikle—B.I.S.R.A., Hoyle Street, Sheffield, 7 p.m.

26th Feb.—Institute of British Foundrymen (London Branch)—Discussion on Test-bars—Constitutional Club, Northumberland Avenue, London, W.C.2, 7.30 p.m.

26th Feb.—Manchester Metallurgical Society—"Metallurgy of Tantalum, Niobium and Beryllium," by Dr. G. L. Miller—Central Library, Manchester, 6.30 p.m.

26th Feb.—Society of Chemical Industry (Corrosion Group)—"Stress Corrosion Cracking of Stainless Steels," by Dr. T. P. Hoar and Dr. J. G. Hines, and "Stress Corrosion Cracking of Carbon and Low-alloy Steels," by Dr. R. N. Parkins—Stephenson Building, King's College, Newcastle-upon-Tyne, 2.30 and 6 p.m.

3rd Mar.—Cleveland Scientific and Technical Institution—"Iron and Steel Works Maintenance," by A. V. Williams—Cleveland Scientific and Technical Institution, Middlesbrough, 6.30 p.m.

4th Mar.—Institute of Metals (Oxford Local Section)—"Nucleation and the Cast Structure," by Dr. V. Kondic—Cadena Café, Cornmarket Street, Oxford, 7 p.m.

4th Mar.—Institute of Metals (South Wales Local Section)—"Metals for High Temperature Service," by Dr. W. Betteridge—Department of Metallurgy, University College, Swansea, 6.30 p.m.

4th Mar.—Sheffield Metallurgical Association—"The Application of Stable and Radioactive Isotopes in Analytical Chemistry," by A. A. Smales—B.I.S.R.A., Hoyle Street, Sheffield, 7 p.m.

6th Mar.—Institute of Metals (Birmingham Local Section)—"The Metallurgy of Steel for Deep Drawing and Pressing—Part II," by A. J. K. Honeyman—College of Technology, Gosta Green, Birmingham, 6.30 p.m.

6th Mar.—Institute of Metals (London Local Section)—"High Purity Iron," by B. E. Hopkins—17 Belgrave Square, London, S.W.1, 6.30 p.m.

6th Mar.—Leeds Metallurgical Society—"Some Metallurgical Problems of Nuclear Energy," by Dr. H. K. Hardy—Chemistry Wing, The University, Leeds, 7.15 p.m.

8th Mar.—Swansea and District Metallurgical Society—"Installation and Maintenance of Open Hearth Furnace Bottoms," by S. R. Isaac—Central Library, Swansea, 6.30 p.m.

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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MINERAL RESOURCES

Airborne Gravity Surveys. H. Lundberg. (*Canad. Min. Met. Bull.*, 1957, **50**, Aug., 465–473). Patterns observed over ore bodies are shown.

Iron-Rich Cordierite Structurally Close to Indialite. M. Sambonsugi. (*Proc. Japan Acad.*, 1957, **33**, Apr., 190–195). A mineral found in Sugama pegmatite is described.

The French Iron Mines. J. Thibault. (*Mét. Constr. Mécan.*, 1957, **89**, May, 415–419.) A review of the economic situation, ore reserves and increase in productivity due to mechanization of the iron ore mines of France is presented. The latest expansion programme is briefly mentioned.—B. G. B.

The Woodstock, N.B., Iron–Manganese Deposits. K. O. J. Sidwell. (*Canad. Min. Met. Bull.*, 1957, **50**, July, 411–416).

Columbium–Uranium Deposits at North Bay, Ontario. J. E. Gill and O. E. Owens. (*Canad. Min. Met. Bull.*, 1957, **50**, Aug., 458–464).

Mineral Deposits of Central America. R. J. Roberts, E. M. Irving and F. S. Simons. (*U.S. Geol. Survey Bull.* 1034, 1957, pp. 205, and maps separate). Iron, chromite, manganese and tungsten ores are noted.

The Problem of Brazilian Iron Ores as Seen by a Geologist. J. van N. Dorr Jun. (*Eng. Min. e Met.*, 1956, **24**, Dec., 365-372). [In Portuguese]. The author suggests that, in the future, the soft, high-grade haematites and itabirites of the Minais Gerais will probably become important although only the hard, high-grade haematite is exported at present. Large amounts of the former ores have to be moved before the latter can be won, and these could compete in the export market if large-scale, cheap transport were available; the potential domestic market cannot absorb the potential production.

The Mineral Resources of Australia. H. G. Raggatt. (*Australasian Eng.*, 1957, **50**, June 7, 65–69). Reserves of Fe, Mn, W, Mo, Cr and other metal ores are briefly noted.

ORES—MINING AND TREATMENT

Iron Ore for Britain's Steel. E. Ford. (*Brit. Steelmaker*, 1957, **23**, Sept., 270–271). A review of home supplies and imports is given.

How to " Work Out " Iron Mines—Twice E. S. Tillinghast. (*Eng. Min. J.*, 1957, **158**, Aug., 94–95). An account of the Pacific Isle Mining Co. operating lower grade ores on properties regarded as exhausted.

Walking Dragline for Opencast Ironstone Quarry. (*Metallurgia*, 1957, **56**, Aug., 67–68). The 1675-t machine with 282 ft jib is described.

Ironstone Mining at Exton Park. (*Mine Quarry Eng.*, 1957, **23**, Sept., 400–405). An account of open-cast mining in Rutland using a W1400 walking dragline.

Dredging Operations over the Hogarth Orebody. W. E. Bennett. (*Trans. Canad. Inst. Min. Met.*, 1956, **59**, 78–87). Recovery of 2×10^6 t of iron ore by dredging in Steep Rock Lake is described.

Stripping Overburden by Hydraulic Dredges. (*Mining J.*, 1957, **249**, Aug. 9, 162–163). An account of operations at Steep Rock Lake, Ontario for working an iron ore deposit is given.

Development of the Inco Iron Ore Recovery Process. (*Trans. Canad. Inst. Min. Met.*, 1956, **59**, 201–207). Production of pyrrhotite concentrate, roasting and reduction to Fe_2O_4 and leaching of Ni, Cu and Co; another process of roasting and selective sulphating, and fine ore agglomeration are described.

Mining Tungsten Deposits by Open Pit Methods Pays at Getchell Mine. W. J. Newman. (*Eng. Min. J.*, 1957, **158**, Aug., 90–93). Methods and costs are outlined for a Nevada location.

Association for the Study of Mechanical Loading in the Lorraine Iron Mines. (*Aciers Fins Spec. Franç.*, 1957, July, 4–29; In English, 10–15). An account of the Association and of the machines used, methods, and output since 1927 is given.

Power Station and Ore Handling Plant at a Scottish Steel Works. (*Engineer*, 1957, **204**, Aug. 16, 234–235). An account of the Ravenscraig power station and the ore unloading equipment in Glasgow.

Modern Iron Ore Preparation, Present State and Development in Germany and Abroad. M. Winkler. (*Technik*, 1957, **12**, Apr., 293–296). Methods of preparation and beneficiation of iron ores are summarized according to type of ore, method, and country.—J. G. W.

The Evolution of Sinter. A. C. Lopes. (*Eng. Min. e Met.* 1956, **24**, Nov., 311–315). [In Portuguese]. Details of the history and modern techniques of making and using sinter are given. The type and capacity of sinter plant in Brazil is set out; a total output of 4400 t per day is expected in 1958.

Second International Symposium on the Sintering of Iron Ores. 1. The Influence of the Preparation of Ore Fines on Sintering. B. Wielandt. (*Preprints*, pp. 16). [In Germany]. Studies on the effects of fuel content, moisture, lime, dolomite and converter roof dust are reported. Methods for working extremely fine ores are described by granulation processes. **2. Sinter Plants of GHH Pan Type for Iron Ore Sinter Production.** P. T. Thomas (pp. 7). [In German]. Square pans are successively carried by crane from a down-draught installation to the tipping point. The plant and its operation are described. **3. The Mixed Firing System, A Process of Saving Solid Fuel in Sintering and Its Influence on Sinter Quality and Output.** H. Rausch and K. Meyer. (Pp. 14; *Iron Coal Trades Rev.*, 1957, **175**, Aug. 16, 389–394). [In German]. A process in which part of the coke breeze is replaced by hot gases from the combustion of liquid or gaseous fuel in a burner hood above the stand is described. Factors such as time and temperature are discussed and the quality of the sinter is given. **4. Evolution of Sintering in Rotary Kilns.** M. Gerard. (Pp. 13). [In French]. Tests made in Belgium are reported in a kiln of 1400 ft^3 capacity and 2° slope revolving twice a minute. Samples were taken from the kiln after cooling and loss of moisture and CO_2, removal of C in the draught, degree of oxidation of the iron and S distribution were observed. Temperatures are also recorded. **5. Sinter Coolers, A. New Integral Part of Modern Sinter Plants.** G. Brandes and H. Wendeborn. (Pp. 9). [In German]. Basic physical data and designs of the various types are given. **6. Blast Furnace Practice with Crushed and Sintered Ore.** A. Roederer. (Pp. 9). [In French]. A description of the Longwy plant is given with operating data on a furnace of 16 ft hearth diameter using increasing proportions of sinter. **7. The Use of Sinter at Dorman Long (Steel) Ltd., Middlesbrough.** J. H. Patchett. (Pp. 23). [In English]. **8. Blast Furnace Practice Using Sinter Burdens at Appleby-Frodingham.** H. S. Ayres. (Pp. 18). [In English]. **9. Preparation of the Burden at the Blast Furnaces of the Société des Hauts Fourneaux de la Chiers.** M. Rondet. (Pp. 7). [In French]. Use of minette ores is described in 5 blast furnaces and typical results with 44–52·5% sinter are tabulated. A Greenawalt plant with 1200 t/day capacity is in operation and a Smidth rotary kiln for 600–700 t/day is being constructed. **10. Some Improvements in Sinter Plant Ignition.** W. C. E. Bell. (Pp. 8). [In English]. A new coke-oven gas burner is described. **11. Assessment Trials on Operating Sinter Plants.** J. M. Ridgion and H. Bates. (Pp. 15). [In English]. An analysis mainly of air requirements and distribution is reported. **12. Trials to Increase the Output of Appleby-Frodingham Sinter Plants and to Improve Quality.** B. L. Robertson, M. Haslam and R. H. Siddons. (Pp. 34). [In English]. Fan operation is reviewed and coke content, available heat and exhaust gases heat content and other factors are then discussed. The importance of pilot plants and the limitations of laboratory testing are considered. **13. Removal of Sulphur During Sintering of Lorraine Iron Ores.** G. Turpin and M. Auxenfans. (Pp. 19). [In French]. Results on high-S, high-Si ore are reported and an analytical study of S removal is made. Sulphides other than pyrites remain in the sinter and S elimination is reduced by higher basicity and by higher coke content. Causes are suggested. **14. The Importance of the Phenomena of Heat Transfer and Combustion in Sintering.** E. W. Voice and R. Wild. (Pp. 23). [In English]. Factors determining the temp. reached in a bed containing fuel are discussed and particularly conditions in a sinter bed. A small scale apparatus with a 3-in. dia. pot is used to study the relationship between heat transfer and combustion. Experiments with various fuels and temperatures, air requirements, fuel reactivity and coke sizes are described. **15. Use of Different Solid Fuels for Iron Ore Sintering.** J. Michard. (Pp. 8). [In French]. Substitution of semi-coke, char, low volatile coal or slimes for coke breeze, optimum size and thermal balances are reviewed. **16. Combustion of Carbon and Thermal Balance in the Sintering Process.** J. Michard. (Pp. 26). [In French]. Composition of gases leaving the sinter is discussed and the method of analysis and the difficulty in measuring CO are described. The thermal balance of the process is then considered. **17. The Effect of Sinter on Blast Furnace Performance at the Margam Works of the Steel Company of Wales Ltd.** J. S. McLean. (Pp. 12). [In English]. **18. The Influence of Suction on the Sintering Process.** B. Menuet-Guilbaud, M. Auxenfans and P. Folie. (Pp. 35). [In French]. Work planned by IRSID at the Saulnes plant is outlined. Suction varied from 400–1800 mm water gauge and results and improvement in production are noted. Carbon combustion and air utilization are reviewed and conclusions are summarized. Methods of analysis are added in an appendix. **19. Blast Furnace Operations with Increasing Proportions of Sinter from Rotary Kilns or Sinter Plants.** J. Paquet. (Pp. 7). [In French]. Tests with 29, 51 and 65% sinter are described and comparisons of rotary kilns and Dwight-Lloyd sinters are made. **20. Sintering Practice at Corby, Northants.** J. G. Colvin. (Pp. 20). [In English]. **21. The Elimination of Sulphur and Other Elements during Sintering.** B. G. Baldwin and L. F. Burgess (see also following abstract). (Pp. 20). [In English]. Ouenza ore with added pyrites was tested in 3-in. and 4-in. sinter pots. A low grade lime-containing ore with added FeS_2 was also used, and then a typical low-grade ore producing self-fluxing sinter. Reduced coke, increased heat supply, preheated air and double layer sintering all improve S removal. **22. A Contribution to the Definition of Physical Properties of Sinters.** J. Michard and A. Matraski. (Pp. 25). [In French]. A discussion of the MICUM test based on the method of examination of coke. **23. An Improved Method of Sintering High Volatile Iron Ores.** R. F. Jennings. (Pp. 13). [In English]. The double layer process is described and compared with the conventional method. **24. Dust Cleaning of Waste Gases From Sinter Kilns.** J. Paquet. (Pp. 3). A summary of the plant installed in Luxembourg. **25. Influence of Various Additions on the Physical Properties of Sinter Made from a Siliceous Iron Ore.** J. A. Boned Sopena. (Pp. 22). [In French]. Sinters of different basicities were made from Paz del Rio ore using lime, limestone, magnesium and raw or calcined dolomite. Physical properties were determined and correlated with oxidation rate. **26. Sintering of Haematite Fines at the Iscor Works, Pretoria.** E. Klein. (Pp. 12). [In English]. **27. A Contribution to the Study of the Mineralogical Composition of Sinter Made from Lorraine Iron Ores.** G. Turpin, M. Angeli, G. Pomey and M. Robert. (Pp. 29). [In French]. Sinters from three ores with coke breeze as the only variable (3–8%) were investigated, primarily to develop methods of study, but also to follow the effect of coke content on mineralogical compositions. Results are given in detail. **28. Blast Furnace Practice with High Sinter Burden at Knutange (France).** M. Brun. (Pp. 11). [In French]. A plant producing 1500 t sinter per day and the use of 60–70% in blast furnaces are described. Compositions are given, changes in coke rate, iron quality, and wear of stack are noted. **29. Study of the Mechanism of Oxidation of Green Magnetite Pellets.** J. O. Edström. (Pp. 26). [In English]. Rates of reaction are calculated for oxidation in O_2 and mixtures with inert gases by observation of a distinct front of penetration. A parabolic law is followed up to 1230° C and O_2 uptake as percentage of complete oxidation is proportional to $(\text{pellet dia.})^2$. The reaction rate constant is calculated assuming it to be diffusion controlled. The equations may be of value in the design of shaft furnaces and Dwight-Lloyd machines.

Elimination of Sulphur and Other Elements During Sintering. B. G. Baldwin and L. F. Burgess. (*Iron Coal Trades Rev.*, 1957, **175**, Aug. 23, 425–433). A review of the chemistry of S removal and of its evolution during sintering is followed by a description of these series of experiments and discussions of the results. The importance of C content is shown, reduction or redistribution of coke in the sinter bed favouring S removal and excessively reducing conditions interfering. Removal of H_2O and CO_2 is also considered. No significant change in P was found and recovery of V was unsuccessful.

The Use of Sinter at Dorman Long (Steel) Limited. A. Ledgard, D. Rist and P. K. Gledhill. (*Iron Coal Trades Rev.*, 1957, **175**, Aug. 2, 249–258). An account with much tabulated data of furnace performance since 1949 with full analyses of ore, coke and sinter and numerous curves showing the effect of burden changes on output.

Sintering of Haematite Ore Fines. E. Klein. (*Iron Coal Trades Rev.*, 1957, **175**, Sept. 6, 549–552). Practice at ISCOR, Pretoria, is described with an account of a pilot plant and of improvements effected on the large scale.

Production of Self-Fluxing Sinter from Fine Concentrates. L. R. Migutskii. (*Metallurg.*, 1956, **1**, (10), 5–7). Production at Cheropovets is described. The storage, handling and analysis of concentrate and the sinter plant with the limestone processing, crushing and mixing systems are outlined. Factors such as size and moisture content are noted and the results of trials given. The conditions for cooling are important, addition of water disintegrates the sinter.

Special Features of Air Circulation in the Sintering Sections of Sinter Plants. A. L. Satanovskii. (*Stal'*, 1956, (12), 1121–1126). [In Russian]. The circulation of air in sintering-machine building is discussed, air- and heat-balances being given. A system adopted at the Dzerzhinskii works in which the sintering machines are totally enclosed, thus enabling process and ventilation air to be separated, is described and recommended.

New Methods of Investigating the Sintering Process. V. S. Abramov. (*Stal'*, 1957, (3), 195–199). [In Russian]. After discussing various Soviet and foreign actual and proposed techniques for studying iron ore sintering the author makes his own suggestions. These include the use of a sintering box with thermo-couples arranged at various depths, which is placed on the strand and in which the charge is subjected to the conditions prevailing along the strand. For measuring air flow through the bed the author recommends thermoanemometers: when measuring permeability the device is placed over the sinter box, when determining air leaks it is placed successively within 200–300 mm of the strand edges and the mean flow calculated.—S. K.

Pelletizing of Fines Increases Agglomerate Production. J. Duda and J. Rádl. (*Hutník*, 1957, **7**, (5), 164–170). [In Czech]. Theoretical and practical aspects of ore pelletizing are surveyed. Experiments carried out by the authors with a pilot plant with a capacity of 50–60 t/m² per 24 h are reported. Granulometry, moisture content of the ore, air permeability of the product, time of pelletizing, inclination of rotary pelletizing pan and other variables were correlated for ores and ore fractions of different types, e.g. Krivoi Rog ores and blast-furnace fines. The results show that pelletizing of fines increases the permeability on sintering and improves its efficiency.—P. F.

Modern Krupp–Renn Processing Plants. J. Mach and O. Olar. (*Czech. Heavy Ind.*, 1957, (7–8), 3–16). An illustrated account with ground plans and perspective views. Whole plants are shown rather than details.

Dust Removal in a Continuous Ore Sintering Plant. B. Weilandt, F. Kruse, and N. Petrusch. (*Stahl u. Eisen*, 1957, **77**, Aug. 8, 1064–1069; discussion, 1074). The authors describe a plant for the continuous sintering of fines and the various sources that cause dust during the process, e.g. dropping from one conveyor to another. The various types of dust removal equipment are outlined and the efficiency of aerodynamic dust removal discussed. Multi-cyclones have an efficiency up to 95%. Additional water spraying reduces the dust to 0·1 g./m³.—T. G.

Dust Removal in a Pallet Sintering Plant. R. Nase. (*Stahl u. Eisen*, 1957, **77**, Aug. 8, 1070–1074). (See also preceding abstract). The author describes the plant and the removal of dust by multi-cyclones. He gives an analysis of the efficiency of dust removal with respect to grain-size and composition of the dust. 94% of the dust was removed by the cyclones.—T. G.

FUEL—PREPARATION, PROPERTIES, AND USES

Proceedings of the Joint Conference on Combustion, 1955, Boston and London. (*Inst. Méch. Eng.*, 1957, pp. 457). **Scientific Principles of Combustion and Their Application.** B. Lewis and G. von Elbe (3–6). A review of physicochemical principles and of flame propagation. **An Appraisal of Combustion Research.** R. A. Sherman and W. T. Reid. (7–13). A review mainly of work on solid fuels. (86 references). **The Chemistry and Physics of Combustion.** (Sir) A. Egerton, O. A. Saunders and D. B. Spalding. (14–33). Oxidation of H_2, CH_4 and industrial gases is treated kinetically, flames, solid-fuel combustion and effects of pressure, burner flames and stability are all reviewed. (72 references). **Instruments as Applied to Detection of Flame Failure.** W. D. Stevens. (47–52). Mainly boiler practice. **Liquid-fuel Firing.** R. P. Fraser. (76–85). Burner operation and control is discussed with reference to boilers. **Combustion of Blast-furnace Gas in Gas Turbines.** A. E. Herskey. (347–353). Tests are reported and it is shown that power plant of this type is competitive with steam or Diesel plants.

Petrography of American Coals. B. C. Parks and H. J. O'Donnell. (*U.S. Bur. Mines. Bull.* 550, 1956, pp. 193).

Jamadoba Central Coal-Preparation Plant. (*Iron Coal Trades Rev.*, 1957, **175**, Sept. 6, 553–556). The new Tata Iron and Steel Co. plant for high-ash coking coals is described.

Automated Feeders for Powdered or Finely Ground Coal. J. Jícha. (*Elektrotechnik*, 1957, **12**, (5), 159–161). [In Czech]. The present state of development of automatic feeding devices for dispensing coal to boilers, coke-ovens etc. is surveyed. Special reference is made to electronically controlled equipment.—P. F.

Progress and Developments Recently Made in the Preparation of Coals for the Purpose of Coking by the Burstlein-Longwy Process. (*Echo Mines*, 1957, July, 396–399). An account of the working and advantages of the plant opened in Sept. 1951 at Thionville, with a list of other plants and illustrations of the installations and of the texture of the metallurgical coke produced.

Study of Structural Changes of Heated Coal. M. O. Holowaty. (*Blast Furnace Steel Plant*, 1957, **45**, Aug. 879–888, 891, 930). Laboratory tests are described on 6 U.S. coals heated in a special apparatus in N_2 with or without a superposed load. Correlation with the Gieseler plasticity index was found.

On the Significance of Dilatometric Contraction. V. Kúdela. (*Paliva*, 1957, **37**, (6), 183–187). [In Czech]. The dilatometric contraction of coals on coking, as measured by the Audibert-Arnu dilatometer, provides the third code number in the international classification of coals. It is shown on the basis of the author's researches that in coals showing only a dilatometric contraction on coking, the degree of contraction can be used as a measure of the plasticity of the coke. The significance of the contraction, and of coal dilatometry as a whole, are discussed.—P. F.

Production of Coke with Low Sulphur from Coal Extract. U. Szües and I. Szebenyi. (*Kohászati Lapok*, 1956, **11**, Jan., 13–18). The purpose of the experiments was the production of electrode coke with a specified low sulphur content, by means of hydro-decomposition of coal and subsequent coking of the extract. The best desulphurizing effect could be obtained by the use of 2% concentration of a catalyst containing chromic oxide and tungsten sulfide in equal proportions. The S content of the coke could be reduced below 1%. Similar results have been achieved with 4% $AlCl_3$ by increasing the yield of coke.—P. K.

Studies on Coking of Extracts from Hungarian Coals. M. Szües. (*Kohászati Lapok*, 1952, 7 June, 132–135). The extracts of Hungarian coals obtained by chemical extraction at 300–430° C were examined for their applicability for coking. The coking was carried out in a closed system at 700° C. Under such conditions the extracts with tetralin could be coked with a higher yield than those with cresol, and the lower temperature extracts gave generally more coke than the higher temperature extracts. The ash content of the cokes is small, between 0·1–0·3% and satisfies the requirements of electrode coke, but the S content of 1–2% is higher than permitted. However it can be reduced to a minimum amount by using a proper catalyst. The production of electrode coke from coal extracts is only economic in a hydrogenation plant. There the hydroaromatic middle oil can be used as a solvent and afterwards it can be treated in the usual way.

New Source for Coke. (*Steel*, 1957, **141**, Aug. 12, 76). A high purity coke is produced by American Gilsonite Co., from a freak deposit of a solid hydrocarbon; its nature, production and uses are briefly described. Sulphur content of the coke is less than 0·25%. It may be used for making the finer steels, alloys, aluminium and anodes. Production will be 275 tons per day.—D. L. C. P.

Fuel Oil in the West German Iron Industry. H. Wübbenhorst. (*Radex-Rundschau*, 1957, May, 541–554). From 1952 to 1956 the consumption of fuel oil by the iron industry has quadrupled. Its use has increased considerably in O.H. furnaces and at the same time the use of producer gas, coke-oven gas and blast furnace gas has fallen off rapidly. The economics of fuel oil are considered in regard to initial cost, combustion efficiency and S and V contents. Comparison of fuels for the O.H. furnace is difficult because their influence on furnace performance, e.g. flame temperature and emissivity, and furnace life cannot be determined precisely.

The iron industry has so far been the greatest user of fuel

oil. The oil market developments in the Middle East foreshadow a rapid rise in mineral oil production. The future demand for fuel oil by the iron industry can only be judged in parallel with the coal and gas supplies available in future; also its price in relation to other sources of energy will be a deciding factor.

Waste Gases Turn a Profit. (*Steel*, 1957, **141**, Aug. 12, 132). The Montecatini process is being employed at the Geneva Works of U.S. Steel Corp. to make ammonia, nitric acid, and fertilizer from the hydrogen of coke oven gas and nitrogen from the oxygen plant.—D. L. C. P.

AIR POLLUTION AND SMOKE

Travelling Hood Exhausts Ingot Fumes. (*Iron Age*, 1957, **180**, Aug. 22, 102–103). A system for collecting lead oxide and iron oxide fumes evolved during pouring operations is described. A movable hood is connected to a slotted exhaust manifold; flexible sealing material closes the slot except at the hood, which travels on rails to the required position. Fume is trapped in a multi-bag filter unit.—D. L. C. P.

Scrap Refinery Controls Smoke With Water Scrubber. L. Bykowski. (*Iron Age*, 1957, **180**, Aug. 15, 96–97). A plant installed to clean the fume from a scrap melting furnace is described. It is a Hydro Precipitator Scrubber in which the gases are wetted and forced through a water bath from which the solids settle and the gas escapes. Capacity is over 20,000 ft³/m.—D. L. C. P.

Ultrasonic Coagulation of Industrial Aerosols. R. M. G. Boucher. (*Génie Chimique*, 1957, **77**, June, 163–173; **78**, July, 14–28). The author discusses the principles, apparatus and applications of ultrasonics with special reference to the newer types of generators. Applications include the coagulation of aerosols, with reports on advances in plant engineering and examples of uses.—R. P.

REFRACTORY MATERIALS

Silica Bricks for Electric-Arc Furnace Roofs. Transformations during their Use. E. Perez Blanco. (*Inst. Hierro Acero*, 1957, **10**, Jan.-Mar., 4–10). [In Spanish]. A spalled roof-brick from an all-acid, 3-phase, 1·6 t furnace melting iron and making 0·14% carbon steel, with a roof life of about 150 heats, has been examined in detail. Four colour zones, from the original white at the colder end to black at the working face, were observed and each was examined by physical, chemical, and mineralogical means; the data are presented graphically. It is shown that the working face of the brick is basically tridymite which suggests that the roof temperature cannot exceed 1470° C in this type of furnace. Thus other bricks, such as the 42/44% Al_2O_3 type, more resistant to thermal shock, could be used with advantage.

The Use of Native Chrome–Magnesite Refractories for Small Open-Hearth Furnaces. M. Harnisch, R. Radtke and E. Schneeweiss. (*Giessereitechn.*, 1957, **3**, Apr., 78–79). Native chrome–magnesite refractories are not yet used in completely basic furnaces, but the partial use of this material in mainly acid furnaces offers advantages, as illustrated by the example of 10-t furnaces in a steel works.—L. J. L.

Studies on Special Basic Refractories from Dolomite and Chlorite. S. Nagai and T. Fujii. (*Tokyo University, Annual Report of the Engineering Research Institute*, 1957, **15**, No. 2, March, 90–94). A study to determine whether the slaking property of dolomite refractory can be excluded by adding hydrated Mg aluminosilicate. Dusting property depends upon free CaO from dolomite; colour, cracks, shrinkage and porosity depend on chemical composition, and compressive strength, spalling property, slaking character and refractoriness depend upon composition and firing temperature.

Versatile New Refractory. (*Chem. Eng.*, 1957, **64**, Aug., 172, 174). SiC bonded with nitride is described.

Relationships between Constitution and Properties of Silica Refractories. Part 1. Effects of the Devitrifying of Silica Glass. A. C. D. Chaklader and A. L. Roberts. (*Trans. Brit. Ceram. Soc.*, 1957, **56**, July, 331–342). The properties of suitable specimens of silica glass before and after progressive devitrification were studied in an investigation of the influence of phases present on the properties of silica. It was shown that the development of comparatively small amounts of crystals within the glass can produce substantial increases in viscosity. It is suggested that this effect contributes materially to the strength of silica refractories—D. L. C. P.

New Materials that the Design Engineer Should Know About: Ceramics and Refractories. J. H. Koenig and E. J. Smoke. (*Mech. Eng.*, 1957, **79**, Aug., 725–727). Refractories, vitreous enamels and cermets are briefly reviewed.

Refractoriness-under-load Properties of Silica Bricks. H. R. Lahr and C. W. Hardy. (*Trans. Brit. Ceram. Soc.*, 1957, **56**, Aug., 369–388). Roof trials on O.H. furnaces are reported. Apparatus for laboratory testing of refractoriness under load is described and the results appear to correlate with O.H. performance.

Some Problems of Refractories in View of the Spreading of Oil Heating in Open Hearth Practice. B. Selmeczi. (*Kohászati Lapok*, 1953, **8**, Feb., 25–33). A comprehensive review is given of the composition, physical and mechanical properties, use and durability of silica, magnesite and chrome-magnesite bricks in O.H. furnaces.—P. K.

Syllabus of Clay Testing. T. A. Klinefelter and H. P. Hamlin. (*U.S. Bur. Mines Bull.* 565, 1957, pp. 67). Refractory uses are included and general testing methods for all purposes are indicated.

On the Bursting of Chrome–Magnesite, Magnesite–Chrome and Chromite Refractories. W. Harjes. (*Neue Hütte*, 1957, **2**, Apr., 231–234). Bursting is defined as the decay of chrome–magnesite minerals due to the action of iron oxides at high temperatures. Laboratory studies were undertaken on 6 basic minerals containing chromite to obtain information on the nature and intensity of "bursting". It appeared that the porosity of the minerals had some effect on "bursting" intensity, less porous varieties being less affected by it.—L. J. L.

The Testing of Refractory Bricks for Temperature-Change-Stability, III. N. Skalla. (*Radex-Rundschau*, 1957, May, 596–598). In this, the third of a series of articles on thermal shock testing, an acetylene burner testing method is reviewed. The principle of the method of testing is the heating of the surface of a refractory brick for 10 minutes with a well defined flame and observing, on two prepared surfaces, the occurrence of cracks, observations being continued for 5 min during cooling. The standard burner used for heating the brick is described. It uses acetylene as the heating gas at 0·10 l./sec. The test procedure consists of drying the brick at 100–105° C and standing for 24 h in air, smoothing and rubbing with chalk of two test inspection surfaces, and setting it up in a clamp with the test surface 10 mm from the burner mouth. The time of heating is taken by stop-watch. The cracks which occur are of three types: (1) normal to the surface, (2) parallel to the surface, and (3) oblique to the surface tending to cause spalling at the corners. A formula for evaluating the brick quality is given. This ignores cracks type 1, and is based on the time of occurrence, mainly of cracks of type 2 but also of type 3, during the 15 min observation period. The evaluations have given good agreement with performance values of bricks in boiler furnaces. In conclusion other thermal shock tests are discussed.

The Temperature-Change-Stability of Different Basic Refractory Bricks. W. Harjes. (*Radex-Rundschau*, 1957, March, 501–507). The temperature-change-stability of thirteen basic bricks of different makes was determined by measuring the maximum elongation and linear dilatation according to the formula $T_w = \frac{\epsilon \max}{\alpha}$ ° C. The T_w values obtained ranged between 17° C (Radex-MD) and 636° C (Radex-EZ). It is concluded that the values afford useful conclusions in regard to future performance in operation. A bibliography on magnesite and chrome-magnesite brick is added.

Determination of the Thermal Conductivity of Insulating Bricks. F. R. Himsworth. (*Trans. Brit. Ceram. Soc.*, 1957, **56**, July, 345–355). The application of Angstrom's method to determining the thermal diffusivity of low-conductivity brick is considered and illustrated. The test is simple and gives results in agreement with more elaborate methods.—D. L. C. P.

The Relation between Crystalline Structure and Reducibility of Dolomite. T. Gedeon. (*Kohászati Lapok*, 1955, **10**, Dec., 536–538). The author discusses the relation between the crystalline structure and the reducibility of dolomite. Steam has a catalytic effect on the lattice transformation. Thus it improves the reducibility and lowers the heat requirements for reduction.—P. K.

The Use of the S.K. Porosimeter for Measuring the Porosity of Refractories. J. Baron. ("*Bulletin de la Société Française de Céramique*," 1956, **33**, Oct.-Dec., 25–31., *IRSID reprint*).

The S.K. porosimeter which is generally used for investigating iron ores and sinters is described. It is shown that total porosity may be broken down into: closed porosity, microporosity, medium porosity and macroporosity. Results obtained with iron ore sinters and refractories are compared with those obtained from the standard method. It is suggested that although the results are of too preliminary a nature to draw conclusions they indicate an interesting picture of the distribution of porosity.

Sub-microscopic Structure of Active Magnesium Oxide. L. Bachmann. (*Radex-Rundschau*, 1957, May, 564–577). Examination by microscope, electron-microscope and X-ray methods of active magnesia prepared by decomposing synthetic and natural magnesia (at 750 to 850° K and vacuum to 700 mm Hg) show that it consists of a porous mass of periclase crystals which vary in size from 50 to 1000° A. There is no orientation among them nor any essential lattice-defects.

The high degree of dispersion of the oxide produced under the given conditions enables even the highest excess energies measured on such samples to be explained in terms of particle size effect. Depending on the temperature of preparation, the size of the magnesia particles shows a minimum, which corresponds to the often observed maximum of catalytic activity and heat of solution. The particle size of the oxide is also influenced by the gas-phase so that the size of the magnesia crystals increases with increasing gas pressure. These phenomena can be explained by consideration of the rate of formation of nuclei and rate of growth of the oxide particles.

IRON AND STEEL—GENERAL

How to Assure Greater Efficiency in the Metallurgical Industry in 1957. L. Šajch. (*Hutník*, 1957, **7**, (5), 149–151). [In Czech]. Various sources of waste are discussed, e.g. incorrect granulometry of coke in coking, inadequate use of exothermic and other methods of reducing ingot-head losses, excessive throwout from blast-furnaces, slow introduction of negative tolerances in rolling of shapes, need for further rationalization of the thermal regimes of blast furnaces and O.H. furnaces, etc. New methods need to be introduced, e.g. homogenization of ores and the use of superheated steam and high-temperature blasts in blast-furnaces, extension of the use of O_2 in steelmaking, and the introduction of vacuum casting.—P. F.

Trends in Research on Iron and Steel. F. Wever. (*Berg- u. Hüttenmänn. Monatsh.* 1957, **102**, Mar., 29–39). A lecture to the Eisenhüttentag Leoben June 1956. An historical account covering the whole field of research on iron and steel.—T. G.

Aspects of the Raw-Materials Supply of the Iron and Steel Industry Within the European Community for Coal and Steel. R. Mayer. (*Stahl u. Eisen*, 1957, **77**, July 25, 977–980). Address of the President of the European Community for Coal and Steel to a meeting of the Wirtschaftsvereinigung Eisen- u. Stanlindustrie, Düsseldorf, June 1957.—T. G.

Société Anonyme des Hauts-Forneaux de la Chiers. (*Aciers Fins Spec. Franç.*, 1957, July, 108–124; In English, 113–117). A brief description of the mines, lime-kilns and the Blagny and Vireux works is given with historical introduction.

The West German Iron and Steel Industry and Its Position Within the European Community for Coal and Steel. H. G. Sohl. (*Stahl u. Eisen*, 1957, **77**, July 25, 983–988). Presidential address to a meeting of the Wirtschaftsvereinigung Eisen- und Stahlindustrie, Düsseldorf, June 1957.—T. G.

On the Development of Iron Industry in Portugal. P. Cabral de Moncada. (*Dissertation, Mining Academy, Clausthal*, 1956, pp. 35). The requirements of Portugal for iron and steel are discussed in relation to local raw materials. Insufficient scrap is said to be available. Several methods of producing iron and steel are reviewed from the economic point of view. It is concluded that careful management might ensure that production costs in Portugal might be competitive with other countries.—R. P.

Heat and Power Economies of an Integrated Iron and Steel Works in the Course of Recent Technical Progress. H. Weineck. (*Stahl u. Eisen*, 1957, **77**, July 25, 988–998). The latest tendency in integrated iron and steel works is to produce electric rather than mechanical power by means of gas engines using flue gas. Only 6% of the electric power required had to be purchased.—T. G.

Energy Economies in an Integrated Iron and Steel Works. F. Stolzenberger and H. Tiemeyer. (*Stahl u. Eisen*, 1957, **77**, July 25, 998–1006). Energy economies of an integrated iron and steel works having O.H. furnaces only is described and the utilization of waste heat from various sources discussed.

Granite City Steel Company A Provider of Iron and Steel Since 1878. C. Longenecker. (*Blast Furnace Steel Plant*, 1957, **45**, Aug., 858–878). An illustrated account is given of the coke ovens, blast furnaces, O.H. shop, slabbing and strip mills and finishing lines, with plan.

New Methods in Metallurgy. E. Cotel. (*Kohászati Lapok*, 1953, **8**, Jan., 9–13). The author reviews the development of low shaft furnaces, converter process with O_2 blowing and continuous steel casting.—P. K.

All-Union Conference of Rationalizers, Inventors and Innovators in Industry. I. M. Krasinskii. (*Stal'*, 1956, (12), 1138–1139). [In Russian]. An outline is given of a conference held in Moscow in 1956 at which 70 representatives of the iron and steel industry were present and many examples of the development and adoption of progressive methods in Soviet steelworks were given. Figures on the number of ideas submitted and adopted in recent years are shown, with estimates of the corresponding savings.—S. K.

Canadian Iron and Steel Boosted by New Inventions. (*Canadian Metalworking*, 1957, **20**, July, 30, 32). Work at the Ontario Research Foundation on iron ore processing, pig iron production from fines in a jet smelter and a direct steel process is outlined.

The Iron and Steel Industry in Australia. I. H. Carne. (*Australasian Eng.*, 1957, **50**, July 8, 49–56). A general account is given of sources of raw materials, Newcastle and Port Kembla Steelworks and Whyalla, and the outlook for the future.

The Growth of the Chinese Steel Industry. (*Australasian Eng.*, 1957, **50**, July 8, 62–64). A brief illustrated account, mainly statistical.

The Use of Oxygen in Metallurgy. A. Tetmayer. (*Kohászati Lapok*, 1952, **7**, Oct., 217–229). A short review is given of the use of O_2 in the blast, low-shaft, O.H., electric arc and cupola furnaces, as well as in converters and gas producers, and its many advantages and few disadvantages are considered.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Economic Characteristics of Pig Iron Production in the East German Republic. J. Tischendorf and H. G. Strauss. (*Neue Hütte*, 1957, **2**, May, 269–280). Raw material resources are reviewed; blast furnace and low shaft furnace operations are discussed; bloomery processes, acid smelting, and ore dressing are examined.—L. J. L.

Iron Balance in Blast-Furnace Production. L. L. Zusman and N. F. Sklokin. (*Stal'*, 1957, (3), 264–267). [In Russian]. Data are presented on the utilization of iron in primary and secondary iron-making raw materials in the Soviet Union as a whole and at individual works, mainly for 1939, 1951 and 1955. A general improvement is evident and this is attributed to improved blast-furnace and ore preparation practice.—S. K.

Operating a Blast Furnace at a Top Pressure up to 1·3 atm. (gauge). E. G. Teterevyatnikov and V. N. Andronov. (*Stal'*, 1957, (3), 200–204). [In Russian]. The modifications made and recommended for the construction of a 1033 m^3 blast furnace and its equipment associated with raising the top pressure in the stages 0·2, 0·8–1·0 and 1·0–1·3 atm. gauge are described and operating results given. The main results of the increase were 6·0–9·5% higher productivity, 3·5–5·0% lower coke rate and a reduction of flue-dust output to $\frac{1}{4}$–$\frac{1}{5}$; furnace working became more even. The charging cycle had to be changed to counteract the tendency of the gas to flow peripherally. More effective use can be made of high top pressure operation with a sintered than with an unprepared burden.—S. K.

Investigation of the Wear of Blast Furnace Hearths and Optimum Design for Air Cooling Systems. S. M. Andon'ev, O. V. Filip'ev and G. A. Kudinov. (*Stal'*, 1957, (8), 685–690). Penetration of liquid iron into the hearth lining has been substantially reduced by air cooling beneath the hearth. Thermocouples are used at various levels for temperature control. Diagrams of hearth wear are given for various furnaces at different works and relations between such factors as temperature at various levels and degree of wear are shown graphically.—R. S.

The Calculation of Capacity and Economic Coke Consumption of Blast Furnaces. G. Szöke. (*Kohászati Lapok*, 1955, **10**, Nov., 481–490). A method is given for calculating the

capacity and determining economic coke consumption of blast furnaces.—P. K.

The Reduction of Coke Rate in Pig Iron Production. L. Visnyovszky. [(*Kohászati Lapok*, 1953, **8**, April 78–80; May 97–107; June 121–126). The author discusses comprehensively the possibilities of the reduction of coke rate in blast furnace practice. The charging of lime and dolomite instead of limestone and the reduction of slag volume and basicity are favourable for this purpose. Unfortunately this reduction promotes the absorption of sulphur in iron.—P. K.

"Gas Flow in the Blast Furnace." V. K. Gruzinov and V. A. Smoliak. (*Stal'*, 1957, (8), 691–692). A review of the book by N. N. Chernov.

Ways of Improving Blast-Furnace Operation Indices. F. A. Khil'kevich, G. V. Mantukhov, B. L. Lazarev and S. V. Bazilevich. (*Stal'*, 1956, (12), 1061–1067). [In Russian]. Blast-furnace practice at Novo-Tagil' is characterized by an irreducible burden (ore/sinter mixture) of variable quality and iron content and with a relatively low-melting gangue. In this article an account is given of changes in practice and the experiments which preceded and followed them since 1950. In this period the coefficient of utilization of useful volume has improved from 0·855 to 0·734 and the coke rate has fallen from 0·814 to 0·691. Experiments included determination of reduction rates of the ores and sinter at various temperatures (optimal temperatures being found for each) both in a laboratory apparatus and by allowing samples to descend to various depths in the furnace. Extensive explorations were also carried out in the furnaces, the distribution of pressure-drop for different top pressures, of temperature and of CO_2 content. The increased productivity of the furnaces is attributed mainly to (1) the raising of the ore/coke ratio with a blast-temperature increase from 595° to 842° C made possible by an increase in the blast-moisture from 8 to 18 g/m³; (2) the adoption of high top pressure (0·6–0·8 atm. gauge); (3) better utilization of the thermal and chemical energy of the gases by controlling gas flow through changing conditions. Further measures envisaged are the raising of top-pressure to 1·0–1·5 atm. and of sinter basicity to 1·3–1·4. Based on the observation that blast humidities > 20 g/m³ lead to higher coke rates it is proposed to use changes in humidity rather than blast-temperature to control thermal conditions in the hearth.—S. K.

Pig Iron Production Using Air Rich in Oxygen. L. Visnyovszky. (*Kohászati Lapok*, 1952, **7**, July, 162–167). The use of air with max. 30% O_2 in blast furnaces furthers the reduction and desulphurization, increases the slag basicity and metal (iron, iron-alloy) output and decreases the coke consumption. In low shaft furnaces it is possible to produce pig iron using brown coal, or carburized lignite as fuel and air with min. 50% O_2. The by product is a top gas of high (2000–2500 Cal.) heating value, which is very suitable for metallurgical purposes.

Production of Basic Pig Iron Using Oxygen-Enriched Blast. I. P. Bardin, S. K. Trekalo, A. F. Zakharov, F. A. Khil'kevich and B. L. Lazarev. (*Stal'*, 1957, (8), 673–684). Smooth operation is obtained without increase of moisture by raising the blast temperature 35–45° C above normal. Iron output increased but gas evolution rate remained constant. Normal gas stream distribution was preserved and this decreased coke consumption. CO_2 concentration increased, going up the furnace more rapidly than with a normal blast, due to improved reducing capacity. With enrichment up to 23·3% O_2, productivity after 14 days increased 6·7% with unchanged coke consumption. The cost was increased by the high cost of O_2 at Nizhne Tagil (15 copecks/m³) by 2·40 roubles per ton. The lines of the blast furnace are shown, and the properties of the ores and sinters, with comparisons of normal and enriched blast are shown, as are materials balance sheets. Sources of cheap O_2 are required, suitably from large generating installations.—R. S.

The Novo-Tagil' Metallurgical Works in the Sixth Five-Year Plan. A. Zakharov. (*Stal'*, 1956, (12), 1059–1060). [In Russian]. The works director reviews recent developments, achievements and failures at Novo-Tagil' and discusses plans for the next few years. An outstanding development at this works is the use of O_2 in a large blast-furnace making basic iron, resulting in a 7% increase in productivity.—S. K.

Improving the Stability of Blast-Furnace Refractory Linings. F. A. Khil'kevich, S. V. Bazilevich and B. L. Lazarev. (*Stal'*, 1956, (12), 1067–1072). [In Russian]. Experience and experiments at Novo-Tagil' with various types of lining and coolers in the hearth and stack are surveyed, most attention being devoted to the stack. For the hearth pad accurately ground and interlocking firebricks over carbon blocks is recommended. Great improvement in stack life was obtained by arranging stack coolers to form almost complete rings, the recommended final solution for the particular practice at the works (high-zinc, low-melting burden) being peripheral plate coolers with carbon brick for the lower part of the stack.—S. K.

The Relining of Newcastle's No. 2 Blast Furnace. H. H. Shaw. (*B.H.P. Rev.*, 1957, **34**, June, 11–13). An illustrated account.

General Repair of a Blast Furnace with the Preservation of Part of the Lining. V. I. Bodrov, M. G. Ermolov and V. I. Bogachev. (*Stal'*, 1957, (3), 274). [In Russian]. Extensive repairs to a 1233 m³ blast furnace are described in which 188 m³ of sound upper stack lining were left in position during relining.—S. K.

Changing Blast-Furnace Charging Gear at the Novo-Tagil' Metallurgical Works in Two Days. S. D. Gladunov, M. T. Levenskikh and P. F. Yakovlev. (*Stal'*, 1956, (12), 1134–1135). [In Russian]. A brief account is given of two occasions on which the complete charging gear on a blast furnace was changed during a campaign. A team of 134 men was used and special care was taken to ensure the correct alignment and fitting of the gear both before and after installation.—S. K.

Low-Shaft Furnaces. L. Szeless. (*Kohászati Lapok*, 1952, **7**, Dec., 280–282). A short review is given of the development, practice and economy of low shaft furnaces in East and West Germany.—P. K.

Production of Refined Iron of Spheroidal Quality in the Electric Furnace by Reduction of Sardinian Iron Ore. G. Zuliani. (*J. Four. Elect.*, 1957, **66**, Mar.-Apr., 59–62). The analytical specification for iron suitable for spheroidal castings is first explained. The analyses of Sardinian ores are given and the practice at the Cagliare Works of S.A.E.M. is described showing how it is possible to make irons of different quality by blending the raw materials.—B. G. B.

The Effect of the Addition of Hydrogen to the Reduction Gas on the Degree of Reduction of Native Iron Ores. H. Braun and K. Wachtl. (*Neue Hütte*, 1957, **2**, June, 333–340). Reaction experiments have been made with Büchenberg and Badeleben ore in a CO–H_2–N_2 mixture, the concentration being so chosen as to correspond approximately with those obtaining in the blast furnace. With H_2 additions of 2, 3, 5 and 20% an increase of the degree of reduction was observed even at 550° C.—L. J. L.

On the Effect of Catalysts on the Reduction of Iron Ores with Hydrogen. W. Machu and S. Y. Ezz. (*Arch. Eisenhüttenwesen*, 1957, **28**, July, 367–371). The catalytic effect of some 100 pure substances or mixtures of substances on the reduction of Aswan iron ore by H_2 has been studied. Cu, Ni and Pt were found to have a positive and W a negative effect. The catalytic effects were only observed at temperatures between 250–400° C—L. J. L.

Experimental Electric Smelting of Ilmenite to Produce High-Titania Slag and Pig Iron. G. E. Viens, R. A. Campbell and R. R. Rogers. (*Canad. Min. Met. Bull.*, 1957, **50**, July, 405–410). Use of a 3-phase 250 kv.a. open-top furnace with $-\frac{1}{4}$ in. ore or $-$ 14 mesh ore either briquetted or by the dry-top method is reported. A slag with 82·5% TiO_2 was formed.

Factors Affecting the Life of Pig-Iron Mixers. A. Latour. (*Stahl u. Eisen*, 1957, **77**, Aug. 22, 1122–1126). The author reports on improvements effected in the life of a pig-iron mixer at Völklingen. The magnesite bricks of the top layer of the lining were ground to measure and only dry magnesite flour was used for setting. Special expansion joints of 12 mm. each were provided. Heating-up was done most carefully with gas. Careful heating supervision during service contributes to reduction in the wear of the bricks; proper limestone addition is another factor. The total service life of the mixer was increased from 9 to more than 36 months.—T. G.

PROPERTIES, TREATMENT AND USE OF SLAGS

A Thermodynamic Study of Fe–Ca–P–O, Fe–Ca–Si–P–O, and Some Complex Molten Silicophosphate Systems. E. T. Turkdogan and P. M. Bills. (*J. Iron Steel Inst.*, 1958, Feb., **188**, 143–153). [This issue].

PRODUCTION OF STEEL

Some Metallurgical Problems of Mild Steel Production. I. Balsay. (*Kohászati Lapok*, 1952, **7**, Nov., 249–263). The use of mild steels for deep drawing sheets, hot and cold pressing, boiler plates, free cutting bars, tubes, welding rods and special physical requirements is reviewed. The chemical composition and mechanical properties, purity, both inside and at the surface, and structure of rimming-, semi-killed, killed- and age-resistant mild steels are discussed. The metallurgical conditions for a satisfactory mild steel quality, such as high melting temperature, adequate firing rate, low S in fuel, heat resistant refractories, suitable slag formation, deoxidation and degassing are considered. The advantages of the use of O_2, as well as of ingot casting in Pb or Bi vapor are deliberated. The measurement of the steel temperature and the assessment of purity with the Bioptix pyrometer are described.—P. K.

Present Problems of Steel Making. I. Balsay. (*Kohászati Lapok*, 1953, **8**, March 70–72; May 108–115). The author reviews the development, economy, productivity and technique of various steel making processes. The conditioning of pig iron in the mixer, converter or ladle, the desulphurizing of pig iron with lime powder in heated rotary furnaces, the use of oxygen and high heat resistant refractories in O.H. furnaces and the Perrin process are some of the main features of up-to-date steel making processes. Hungarian experiments on pig iron conditioning are described.—P. K.

All-Union Steelmakers' Conference. O. A. Mikhailov. (*Stal'*, 1957, (8), 715–717). A Conference at Sverdlovsk in May 1957 was attended by 800 steelmakers and engineers. Discussion included the use of O_2 in O.H. and electric furnaces and converters, especially O.H. furnaces of 250–500 t capacity, the continuous casting of steel, vacuum treatment of steels and alloys. Steel output in the U.S.S.R. for 1956 was $48{\cdot}6 \times 10^6$ t, 90% from O.H. furnaces, 52% of which was from furnaces of 200-t capacity or larger. The best 370-t furnaces produced 34 t/hr. Chrome-magnesite roofs have been extensively adopted and last 2–3 times as long as silica roofs. In 1956, 79% of all O.H. and 49% of all arc furnaces had chrome–magnesite roofs. In 1956, at Dnyeprospetstal, a vacuum treatment for steel before casting was developed. Electric and gas heating of feeder heads have improved yield and structure. In 1955 there were 8 continuous casting plants in operation for both rimming and killed steels. An 18% rise of labour productivity in O.H. plants is claimed for the two years. In 1956 many plants did not reach the planned output and there was too much down time. Full advantage has not been obtained from the use of O_2 and there is insufficient defuming equipment for waste gases. Waste heat boilers in O.H. plants are not being developed sufficiently rapidly, there have been shortages of scrap due to lack of preparation plants and more standardization and sorting is needed. Damage to converter linings from the use of O_2 remains a problem. Large arc furnaces have fallen behind schedule and induction stirring has not been installed quickly enough. Building of large O_2 plants is too slow. More vacuum induction furnaces of ½, 1, and 3-t capacity for heat-resisting alloys are required and vacua of 10^{-4} mm must be obtained. It was stated that a 700-t O.H. furnace was to be developed by the State Planning Organizations.

Comparison of the Economics of Steel-Making Processes. R. V. Bregman. (*Stal'*, 1957, (3), 268–272). [In Russian]. On the basis of analyses of operating and capital costs of modern O.H. furnaces and top-oxygen-blown converters for Soviet conditions, the author concludes that both types should be used.—S. K.

Steel Making Using Surplus Gases from a Plant Manufacturing Sponge Iron. G. Coll, G. Trevijano, M. Espinosa Cilla and J. J. Jauregui Epalza. (*Inst. Hierro Acero*, 1956, **9**, Oct.-Dec., 1081–1119). [In Spanish]. A theoretical mathematical study of the reduction of pure ferric oxide with (*a*) pure CO, and (*b*) pure H_2 is described and extended to the study of the reduction of iron ore with O_2-blown producer gas. It is shown that the surplus gases from the ore reduction can be used for O.H. furnace firing whether using normal charges, or charges of the previously manufactured sponge iron, or mixtures of the two.—P. S.

The Use of Oxygen in the Iron and Steel Industry of Sweden. I. Murzin. (*Stal'*, 1957, (8), 765–767). A review from the literature.

Progress at Ravenscraig. (*Iron Coal Trades Rev.*, 1957, **175**, Aug. 16, 365–372). An illustrated account of the new Colville steelworks.

Fundamental Questions in the Planning and Construction of Steel Works. F. Lüth. (*Inst. Hierro Acero*, 1956, **9**, Oct.-Dec., 1059–1066). [In Spanish]. The basic problems involved in the siting and equipping of an integrated plant of 500,000 t capacity are discussed in detail.—P. S.

Tasks for Plan and Technology of Steel Plants. E. Martinovich. (*Kohászati Lapok*, 1953, **8**, Sept., 185–194). A plan, prepared by the Russian planning institute Gipromez, is described for a steel plant containing four O.H. furnaces each of 120–130 t capacity and one inactive mixer of 600 t. The plan also includes the steel making and casting technology. The production from the furnaces is 14–15 t/hr, melting 75% hot charge and 25% self produced scrap. Total operating time is 88–90%. The furnaces are heated by Venturi port ends with carburetted top gas, or coke-oven gas top gas mixture of 2200 cal/m³. Heat requirements are $16{\cdot}5$ mean, $21{\cdot}5 \times 10^6$ cal/hr or $1{\cdot}15$ mean, $1{\cdot}49$ max $\times 10^6$ cal/t steel. The regulation of the heating equipment is automatic, or manual when necessary. The composition of the hot charge should be: Mn 1·5% max, Si 0·4% max, P 0·2% max, S 0·06% max, which is obtainable only by conditioning the pig iron. The ore should not contain more than 6% SiO_2 and must be correctly prepared. The use of direct oxidation is recommended. The products from the steel plant will be used for rolling plates and sheets.—P. K.

New Ways with Steel. A. Tix. (*Met. Elect.*, 1957, **21**, July, 84–86). [In Spanish]. A brief account of modern techniques in use at the Bochumer Verein plant is given; these include oxygen blowing, vacuum casting, electric resistance heating of stock for rolling, and the powering of a new rolling mill.—P. S.

Results of Tests on B.T.M. Basic Bessemer Steel Made at Senelle in November 1954. M. Thiault and J. Stremsdoerfer. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, (6), 1201–1210). In 1954 48 casts of steel were made by a modified Thomas process designed to give a low content of metalloids (B.T.M.) in the final steel. 8 casts of normal Thomas steel were also made as a control, the results are now given. The steels have been made into a wide range of products at a number of different plants in France. The B.T.M. steels have been found to have superior rolling properties to normal Thomas steel and to be capable of replacing O.H. steels for many purposes.

Study of Desulphurisation in Basic Bessemer Steelmaking. A. Decker. (*Rev. Univ. Min.*, 1957, 9th series **13**, May, 165–212). A comprehensive review of all aspects of sulphur removal in Thomas steelmaking is presented. The review is divided into two parts. In the first, methods of desulphurizing the iron before the convertor are considered. In the second a study is made of factors influencing S removal and its partition between slag and metal in the convertor. The thermodynamic factors influencing S removal, in particular the S activity and O_2 potential, are explained with examples. The theoretical observations are discussed in relation to actual results obtained in practice. (71 references).—B. G. B.

Automatization of Open Hearth Furnaces with Gaseous Fuel. J. G. Mitin. (*Metallurg*, 1956, (3), 16–18). [In Russian]. Various types of automatization and methods of work on O.H. furnaces in a number of Soviet Metallurgical works are briefly described. The work of an integrating gas-meter and an automatic gas analyser in the plan of automatization is discussed.—S. I. T.

Entire Open Hearth Furnace Replaces One No Longer Serviceable. (*Blast Furn. Steel Plant*, 1957, **45**, Apr., 385–387). A description is given of the replacement of an existing O.H. furnace at the Geneva Works of U.S. Steel by a new furnace of 300 t capacity which had been built off the site and which was towed into position.—B. G. B.

Prefabricated Open Hearths. (*Steel*, 195, 1957, **140**, Feb. 25, 94–96; see also Feb. 18, 113). The replacement of O.H. furnaces at Geneva Works, U.S. Steel Corp. by prefabricated 300 ton-capacity units is described. In seven cases the framework was prefabricated. For No. 6 furnace the brick work was also completed before the furnace was transferred to site; it weighed 1850 tons. Downtime was 11 days, a 21 day saving.—D. L. C. P.

An Experiment on Rapid Production of Steel from Phosphorus Cast Iron. F. F. Svizidenko, B. A. Sharov and L. G. Fetisov. (*Metallurg*, 1956, (3), 28–32). [In Russian]. This is a detailed account of the technology and methods of refining

of high-phosphorus cast iron obtained from Kerch ores in the O.H. furnaces of "Azovstal" works. The main features of the successful production are: rapid and hot process, intensification of melting at the expense of rational production of slag by timely addition of preheated lime and ore.—S. I. T.

Faster Charge for Open Hearth. (*Steel*, 1956, **139**, Dec. 24, 70). Modifications for increasing the tonnage of 11 O.H. furnaces are described. 61 ft³ charging boxes can be accommodated; the doors were enlarged to 5 ft × 5 ft and the furnace roofs raised; the new furnace fronts were prefabricated.

On the Work of Open-Hearth Installations in Chelyabinsk and Trans Caucasian Metallurgical Works. M. M. Privalov. (*Metallurg*, 1956, (1), 22–24). [In Russian]. Criticism is presented of the installation and methods of work of certain new O.H. furnaces.—S. I. T.

Increase of Economy and Production of O.H. Furnaces by Installation of Waste Heat-Boilers and Systems of Evaporation Cooling. I. I. Bruk. (*Metallurg*, 1956, (2), 17–22). [In Russian]. Various installations of boilers or systems of evporation cooling, or the two combined, are described. Result of experimental work in respect of economies attained and methods of work are given. It is claimed that the coefficient of heat utilization can be increased up to 40% in the case of boilers, up to 45% in the case of cooling systems and up to 65% with both.—S. I. T.

Production of High Quality Rimming Steel for Automobile Sheets. F. T. Antonyuk and A. I. Marinov. (*Metallurg*, 1956, (1), 24–27). [In Russian]. A large amount of numerical data is provided for the materials and operations of O.H. furnaces producing special sheet steel.—S. I. T.

Experience with the B.I.S.R.A. Burner. K. Schermer. (*Iron Steel*, 1957, **30**, June, 215–218). A comparative trial of the B.I.S.R.A. and another oil burner in all-basic O.H. furnaces, one single and one twin uptake, each of 110 t capacity, was carried out over 50 heats. Full details are given. The B.I.S.R.A., as compared with the "S" burner gave 5·2% increase in melting rate and 3·1% increase in production rate and 5% lower oil consumption in the twin uptake and 2·4%, 0·7% and 2·4% in the single uptake furnace.

Carbon Equivalent Concept. Application to Controlled Charging in the Basic Open-Hearth Manufacture of Quality Forging Steels. K. G. Lewis and J. McCracken. (*Iron Steel*, 1957, **30**, May, 165–169; June, 207–213). The occurrence of hard and soft melts suggests better control of carbon content and using the concept of equivalent carbon the metallurgical load can be calculated. The quality of forgings is used as an index of the improvements obtained and a nomogram for the calculation is developed. (20 references). The effect of oxidation on forging quality is then considered and hairline and other defects are discussed. Variation of metallurgical load is investigated and the results of its control are shown including the effects of lime and increased scrap. The oxidation-melt carbon relationship is derived in an appendix. (22 references).

The Desulphurization of Steel in the Open-Hearth Furnace. H. vom Ende. (*Stahl u. Eisen*, 1957, **77**, Apr. 18, 506–508). The author reviews recent publications on the desulphurization in O.H. furnaces. The ability of the slag to take up the sulphur ($K\cdot(O)$) can be expressed by: $K'\cdot(O) \pm \{(8)/[8]\}\cdot(\Sigma Fe)$. $K'\cdot(O)$ depends, however, on the ($SiO_2 + P_2O_5$) content of the slag which varies at different works, i.e. with the mode of operation and with the composition. It is not yet known whether the elimination of sulphur from steel is feasible via the gas phase.—T. G.

The Use of Oxygen for the Intensification of the Combustion Process in Large Steelmaking Furnaces. L. Kodrle. (*Hutnicke Listy*, 1957, **12**, (1), 2–9). [In Czech]. An analysis is made of the effectiveness of O_2 introduced into large ordinary and tilting O.H. furnaces. The oxygen used was of 70% purity. Additions of O_2 to the gas is shown to be more efficient than enrichment of the combustion air. The conclusions are based on full scale tests carried out in Czechoslovakia, and agree in essence with results obtained in the U.S.S.R., Germany and the U.S.A.—P. F.

Experience with the Use of Oxygen in the 250-ton Open Hearth Furnace. S. I. Lifshits and I. F. Sochan. (*Stal'*, 1957, (5), 402–405). Two O.H. furnaces with chrome-magnesite roofs using 50–55% hot metal and fired with coke-oven, blast-furnace and producer gases with a calorific value of 2240–2470 cals/m³ and a max. heat input of $29·7 \times 10^6$ cal/hr. The steel is cast in 4½ t ingots rolled down to billets of 1¾ to 3½ t. O_2 is fed through 1 in. pipes with water-cooled nozzles during charging, heating, addition of hot metal and melt-down either during one or two of these stages or throughout at a pressure in the main of 5–11 atm. Consumption is 750–1600 m³/h or 8·6–26·5 m³/t of steel (average 16·6). Combustion air is enriched to 25% O_2. With medium C steels, 4–6% ore is added and 7–9% limestone, and for mild steels 7–8% ore and 7·5–8·5% limestone are added. Over 6 months, tap to tap time was reduced 11·4–12%, Mn content of the metal is reduced very little, oxide in slag at melt-down increases but prior to deoxidation the change is small. Rate of carbon fall during ore boil and up to refining increases. Consumption of ore and limestone is reduced and metal temperature after melt-down is increased.

Application of Oxygen for the Increase of Productivity of O.H. Furnaces. A. V. Leskov. (*Metallurg*, 1956, (1), 7–9). [In Russian]. An essential condition for the efficient use of oxygen in O.H. furnaces is the reduction of the time of charging of scrap, standard materials standard process and high quality refractories. A combined method of adding 30% of O_2 to the gases and blowing it vertically downward by water-cooled nozzles on the metal surface is recommended.

Production of Rustless Steel with Oxygen Blowing. N. I. Shutkin. (*Metallurg*, 1956, (1), 10–11). [In Russian]. An installation for gasification of liquid oxygen is described. Oxygen is blown through lagged gas or water pipes. A graph giving temperatures of equilibrium between chromium and carbon helps to select an optimum temperature. The use of oxygen allows a more economic use of scrap, production of steel with a lower percentage of carbon (0·06–0·10%) and a reduction of the time of operation by 23%.—S. I. T.

Radioactive Method for the Determination of Slag Mass during the Basic Open-Hearth Steel-making Process. G. R. Church, W. C. Heselwood and G. A. Nicholson. (*Nature*, 1957, **179**, June 22, 1294–1295). Using the dilution technique, ^{140}Ba was found satisfactory (and the ^{140}La produced). The method was checked by direct weighing of the slag from a 350-t furnace.

Applying Ionic Slag Theory to Explain the Qualitative Character of the Reaction Between Slag and Metal. A. Staronka. (*Hutnik*, 1956, **23**, (10), 375–379). [In Polish]. The oxidizing and desulphurizing properties of slags and the oxidation of steel admixtures are explained on the basis of the ionic theory. Equilibrium equations with reference to various constituents of the slag are deduced.—K. G.

Application of Theoretical Principles to Desulphurization in Iron and Steel Making. J. F. Elliott. (*Amer. Inst. Met. Eng. Blast Furn. Coke Oven Raw Mat. Comm. Proc.*, 1956, **15**, 109–119). Alloying elements and slag composition are considered and applications to the process are discussed. Both blast furnace and O.H. are considered and ladle treatment is mentioned.

Desulphurization with Calcium Cyanamide in Hot Metal Ladles. G. G. Hatch, G. E. Wagner and M. Trottier. (*Amer. Inst. Min. Met. Eng., Blast Furn. Coke Oven Raw Mat. Comm. Proc.*, 1956, **15**, 120–124). Metal with 0·15–0·6% S and 1–2% C can readily be desulphurized to less than 0·035% S with $CaCN_2$. Temperature control is necessary to prevent skull formation.

Problems Connected with Basic-lined Hot-Metal Mixers. H. Parnham. (*Trans. Brit. Ceram. Soc.*, 1956, **55**, May, 339–368). Magnesite linings are described and mixer design, slagging, metal oxide system phase diagrams and recommendations for increasing life are considered. With discussion.

Analysis of Factors which Increase the Output of Electric Arc Furnaces. K. Radzwicki and J. Natkaniec. (*Hutnik*, 1956, **23**, (1), 21–25). [In Polish]. A short analysis of various factors for improving the output of steel in the electric arc furnace is given. The influence of the size and the lining of the furnace, power of the transformer, mechanization of charging, intensification of gaseous O_2 blast, induction stirring and application of duplex processes are briefly surveyed. The ways of increasing the output of steel in the electric arc furnace in U.S.S.R. are summarized.—K. G.

An Automatic System of Fuel Control. D. R. Mathews. (*Iron Steel Eng.*, 1957, **34**, May, 82–88). The author describes the gas balance at Alan Wood Steel Co. and the automatic fuel control installations in the O.H. shop.—M. D. J. B.

Preparation of Scrap for Open Hearth Furnaces. V. W. Jones. (*Iron Steel Eng.*, 1957, **34**, May, 104–107). The author discusses the problem of preparing and supplying

scrap to O.H. furnaces. Some information on pan weights is given.—M. D. J. B.

Operating Experience with Basic Refractories in Open-Hearth Furances. K. Leitner. (*Neue Hütte*, 1957, **2**, Feb.-Mar., 142–150). The use of large, entirely basic furnaces, the causes of wear in refractories, the construction of Radenthein suspended roofs; and the improvement of lower-furnace life, are discussed.—L. J. L.

Some Experiences in Operating Open-Hearth Furnaces having All-Basic Roofs. F. Procháska. (*Hutník*, 1956, **6**, (12), 362–364). [In Czech]. The behaviour of basic roofs of Czechslovak manufacture in practice is discussed. The author considers the introduction of O_2 into the O.H. furnace by other means than through the burners inadvisable.—P. F.

Aerodynamic Constitution of the Open-hearth Furnace. II. Features of Flow in Typical Designs. H. A. Hasimoto. (*Tetsu to Hagane*, 1956, **42**, Dec., 1102–1106). [In Japanese]. Water models were used to study flow patterns in semi-Venturi and Maerz designs, and the single air-uptake design with the single oil burner. The basic flow pattern is described, it is the same for all designs, forming two vortices and a recirculation flow which promotes fuel-air mixing. The main differences in design are in the mechanism of mixing at the incoming end. Double air-uptakes promote mixing at the upper surface of the burner jet, while the single uptake adds mixing under the jet. The latter design seems to be most appropriate for an oil-fired furnace. **III. Functions of the Lower Furnace.** (1957, **43**, Feb., 117–121). Flow patterns were studied on two- and three-dimensional furnace models. In the slag pocket there is a main curving flow in the upper part and three-dimensional vortices below. The fantail does not act as a flow equalizer, but can be improved to give more even flows by sloping the roof downwards to the checker chamber. The flow into the checker chamber tends to pass through the farther side; this can be rectified by fitting deflectors or using double-path chambers.—K. E. J.

The Phosphorus Content in Pig Iron for use in Steelmaking by the Talbot Process in Tilting Open-Hearth Furnaces. A. Děkanovský. (*Hutník*, 1957, **7**, (3), 81–85). [In Czech]. The conditions leading to the formation of P-rich slags suitable for use as fertilizers are analysed.—P. F.

Conversion of High-Phosphorus Pig Iron in Tilting Open-Hearth Furnaces. E. V. Tret'yakov and V. A. Makovskii. (*Stal'*, 1957, (6), 517–519). Furnaces of 350-t with silica roofs were used. Details of heats are given, the amount of metal left in at tapping being varied and varying amounts of slag being left in for killed and rimming steels, and for furnaces with basic roofs. The Dortmund practice is modified and increased productivity is claimed. Air is enriched and self-fluxing sinter and limestone-ore briquettes are used.

Processing of Stainless Scrap by Means of Oxygen in the Open-Hearth Furnace. V. Černý and Z. Zdeněk. (*Hutnické Listy*, 1956, **11**, (10), 579–583). [In Czech]. Details are given of works experiments on the utilization of Ni–Cr and Ni–Cr–Mo steel scrap for the production of stainless steels in the O.H. furnace. Stainless steels of good quality have been obtained in this way. The steels could be rolled with ease, and their corrosion properties were not inferior to similar steels made in the electric furnace.—P. F.

Results of New Studies of Open-Hearth Furnaces, with Special Reference to MAERZ Furnaces. R. Baake and H. Stollberg. (*Neue Hütte*, 1957, **2**, Feb.-Mar., 157–167). Results of tests on O.H. furnaces in the East-German Republic are reported with reference to (1) the operation of generators for lignite briquettes, (2) gas supply to the furnace (3) shape and operation of combustion chambers, (4) reduction of infiltrated air, (4) improvement of flow in O.H. furnaces, (5) improvement of design of top of MAERZ-type furnaces.—J. L.

Development of the Production of Ball Bearing Steel in the Acid Open Hearth. P. P. Semenenko, M. M. Golovanov, and I. G. Fadeev. (*Stal'*, 1957, (6), 503–507). Trial heats are described to avoid non-metallic inclusions. Special pig iron with 0·009% S was used and special care was taken to avoid contamination from refractories. Ingots with 1·45–1·71% C, 0·80% Mn, 0·08–0·09% Cr, 0·12–0·14% P and 0·012–0·014 S were obtained. Blast furnace gas was used for firing at the rate of 8–8·5 × 10^3 m^3/h and low-S fuel oil at 110 lb/t steel. Effects of Mn content and Al, Si–Ca, Si–Zr, Fe–V as deoxidizers are given. Al always increased oxide inclusions. Rejects were greatly reduced.

Open-hearth Furnace Operation by Cold Coke-oven Gas under High Pressure. I. Murata, M. Maeda, and K. Kumai. (*Tetsu to Hagane*, 1957, **43**, Jan., 17–23). [In Japanese]. Furnaces originally designed to use mixed gas have been modified with burners, to use cold coke-oven gas or liquid fuel. Conversion to the use of high-pressure coke-oven gas and operating experience with this fuel are described.

Measurements of the Size of Droplets from Convergent-Divergent Nozzles used in Oil Burners for Steel Furnaces. E. J. Burton and J. R. Joyce. (*J. Inst. Fuel*, 1957, **30**, July, 395–398). Fuel oil was replaced by a blended wax of the same viscosity and the solidified droplets were examined. At 70–300 lb/h with air-fuel ratios of 5–12 lb/gal the median size, except at the lowest rate, ranged from 47–70μ. Neither nozzle profile or distance of fuel pipe from nozzle entrance had appreciable effects on size distribution.

Open Hearth Furnace Liquid Fuel Combustion. H. V. Flagg. (*Indust. Heating*, 1957, **24**, Feb., 310–322). A qualitative analysis is made of the combustion of liquid fuel in the O.H. furnace with special reference to furnace pressures.—A. D. H.

Investigation of Liquid-Steel Temperature. D. K. Pugachev. (*Stal'*, 1957, (1), 30–34). [In Russian]. An account is given of an investigation at Magnitogorsk in which the metal temperature at various stages of the refining period of a 380-t basic O.H. furnace heat and during tapping and teeming was measured with Pt–Rh/Pt immersion thermocouples. From the indications obtained optimal temperatures were found: the maintenance of these before deoxidation and teeming in a ladle with two stoppers and a 30-mm diameter nozzle reduced underfilling at the start of teeming by 0·3–0·9% for rimming steels and crack-rejects by 0·7% for killed steels, the yield of sound metal increasing by 0·3–1·0%.

Influence of Non-Uniformity of the Temperature of the Gas Stream on Heat Transfer in Furnaces. N. A. Zakharikov. (*Stal'*, 1956, (10), 927–933). [In Russian]. In this theoretical work the influence of the comparatively cold layers of gas above and below the flame in O.H. furnaces on heat transfer is considered. The existence of such non-uniform temperatures is shown to modify the whole heat-transfer process, decreasing the total rate of transfer. Where roof temperature is the limiting factor the layer of gas above the flame can be made to serve a useful purpose since, by altering its temperature and degree of blackness, flame temperature can safely be raised. The contradictory results of various investigations on the effect of furnace height can be attributed to failure to consider real temperatures.—S. K.

Use of Compressed Air in Open-Hearth Furnace Ports. V. N. Kazantsev. (*Stal'*, 1956, (11), 984–988). [In Russian]. Good results have been obtained with large O.H. furnaces fired with mixed coke-oven, blast furnace and producer gas, through the injection of air at 4 atm. (gauge) into the ports. This increased the exit velocity of the gas stream from the standard Soviet type of port by a factor of 1·5, leading to a decrease of tap-to-tap time of 40–50 min. The maximal rate of air injection not leading to loss of efficiency was 3500 cu. m./hr. Calculation methods involved in the application of the practice are given.—S. K.

Introducing Oxygen into the Gas Port of an Open Hearth Furnace. V. A. Makovskii and Ch. A. Okinchits. (*Stal'*, 1957, (6), 513–517). An injector is described feeding O_2 at up to 1000 m^3/h, it improves thermal conditions and has a good effect on the gas ports, linings and gas checkers etc. O_2 should be fed during refining and boil as flame control is attained with a consumption of 600–800 m^3/hr and a moderate flame temp.

Addition of Oxygen to the Flame of a Large Open-Hearth Furnace Working on Phosphoritic Pig Iron. Ya. A. Shneerov, V. V. Leporskii, G. N. Oiks, V. T. Sladkoshteev, A. I. Sukachev, E. A. Kapustin, M. T. Bul'skii, and P. N. Slepkanev. (*Stal'*, 1956, (10), 875–882). [In Russian]. Experimental results and operating experience gained mainly at the "Azovstal'" works, where oxygenation of the flame has been practiced in the O.H. shop for several years, are analysed. Oxygenation of the air up to 24–25% in the charging, heating, hot-metal addition and melting periods at "Azovstal'" led, if accompanied by conversion to magnesite-chrome roofs, to a 20% reduction in tap-to-tap time, a 17% increase in productivity and a 12-kg/ton reduction in standard fuel consumption. Flame oxygenation at each stage of the process led to reduction in tap-to-tap time, but the greatest effect

was obtained by oxygenation during charging and heating. Increased oxygenation (up to 29%) with simultaneous reduction in the durations of the earlier stages (charging, heating, hot-metal addition) lead to continual acceleration of the process, reduction in specific fuel rate and increase in specific oxygen consumption; further experiments are necessary to decide the desirability of regular operation with such intense oxygenation. An optimal rate of thermal loading during the charging and heating periods existed for each charging rate, the optimal value rising with increasing rate. Fundamentally, flame oxygenation only increased the rate of the physical-chemical process without affecting either the technology of the overall process or the quality of rail or rimming steel. Because of higher working temperature and increased dust carryover in the combustion products, flame oxygenation increased wear on roofs and back and front walls.—S. K.

Study of the Penetration of Hot-Top Composition Into the Body of the Ingot with the Aid of Tracer Atoms. A. G. Kolesnik and V. N. Maslova. (*Stal'*, 1956, (12), 1130–1133). ([In Russian]. ^{32}P, ^{60}Co, ^{59}Fe, ^{45}Ca and ^{35}S were used as tracers in the investigation described to follow the penetration of hot-top compositions into the body of rail and tube steel ingots. The greatest number of radioactive samples occurred in ingots left quiescent for the shortest time after pouring and in those to which soot or fire-clay had been applied. Radioactivity spread was least in ingots allowed to stand for 60–75 min and those heated with lunkerite. With all three compositions tested the microstructure of the rolled products was satisfactory. Depth of radioactive penetration and C, S, and P segregation were also studied.—S. K.

Core Materials for Cores for Steelworks Ingot Moulds. J. Brickner. (*Gjuteriet*, 1957, **47**, (2), 23–24). [In Swedish]. After the failure at Sandviken to reduce core knock-out times by adding considerable amounts of starch meal, good results have now been obtained by using 70% by weight old sand, 30% new sand, 0·4% coaldust, 0·2% cellulose derivative binder and 5–6% water. Knock-out times are now roughly 2 min.

'Controlled Cooling' of Hot Ingots in a Single-ingot Pit at Appleby-Frodingham. A. Jackson, N. H. Turner, and R. C. Walthew. (*J. Iron Steel Inst.*, 1958, Feb., **188**, 114–118). [This issue].

The Vallak Process of Hot Topping. Report of a Visit to Sweden. J. Duflot. (*Centre. Doc. Sidér. Circ. Inform. Tech.*, 1957, (6), 1227–1238). A description is given of this process of exothermic hot topping which was seen in use at 4 Swedish works. Two types are in use, in one only of which recarburization of the steel at the head of the ingot takes place. The process uses four exothermic tiles. The results obtained are discussed and the costs of the process are considered.

The Present State of Continuous Steel Casting. F. Árkos. (*Kohászati Lapok*, 1953, **8**, June, 126–137). A review is given of the development of technique and equipment for continuous steel casting. Reference is made to the productivity and economy of this method.—P. K.

Continuous Casting of Steel in the U.S.S.R. M. S. Boitchenko and V. S. Rutes. (*Hutnické Listy*, 1957, **12**, (6), 500–509). [In Czech]. A detailed account is given of processes and likely developments of continuous casting. The plant installed at the "Red Sickle," "New Tula" and "Red October" works are considered and their respective merits assessed. Design, casting technology, layout and metallurgical aspects are treated.—P. F.

Rational Design of the Mould for the Continuous Casting of Steel. G. I. Kozlitin and I. N. Kolybalov. (*Stal'*, 1957, (3), 209–213). [In Russian]. Based mainly on experience at the "Krasnyi Oktyabr'" works the performance of three types of mould are compared: stationary, sprung and reciprocating. Details are given of the construction of the stationary and reciprocating moulds and of the actuating mechanisms for the latter. The possibility of considerable lightening and cheapening of the reciprocating self-aligning moulds, which has eliminated hanging of the billet, was indicated by experience with stainless steel in 1956. Remote control of the casting operation has become possible and its automation is envisaged.—S. K.

Continuous Cast Bars for Working in Rolling Mills and Forging Shops. J. Hofmaier. (*Berg-u. hüttenmänn. Monatsh.*, 1957, **102**, April, 125–135). The continuous casting plant at Kapfenberg is briefly described, in which rounds and squares in a variety of steels including stainless steels and high-speed cutting steels are produced. The author discusses the properties of continuous cast bars and the shortcomings in their use by rolling mills. He reports that continuous cast bars were found very satisfactory for drop forgings and pressings. He concludes with economic aspects of the process.—T. G.

Porosity of Raw Steel Ingots (300 Kg) of C22 Quality for Wheel Disc Production. G. Wycisk and O. Kramer. (*Neue Hütte*, 1957, **2**, June, 341–346). Initial C and Mn contents were found to have no clear connection with porosity, but the effect of these in the last furnace-control test and of the rate of decarburization during the last hour was established beyond doubt. Nor is there any doubt that these affect the O_2 content of the steel bath before pre-deoxidation. For this reason, the maximum Si content of the final test was increased, in 1955, from 0·35 to 0·45%.—L. J. L.

PRODUCTION OF FERROALLOYS

Experimental Electric Smelting of Manganese Ores. R. A. Campbell, G. E. Viens and R. R. Rogers. (*Trans. Canad. Inst. Min. Met.*, 1956, **59**, 174–180). Studies on 5 low-grade ores are reported, producing Fe–Mn, Si–Mn and spiegeleisen. Large laboratory scale work shows the possibility of working the processes in one to three stages.

Mechanization of Charging in the Smelting of High-Silicon Ferroalloys. A. I. Aleinikov. (*Stal'* 1957, (3), 277–279). [In Russian]. Charging mechanisms used at three Soviet ferroalloy works in the production of high-silicon alloys are described and the characteristics of various types discussed. The author suggests that the simplest (e.g. chute) types are satisfactory.—S. K.

Oxygen Plant Fills Dual Role. (*Chem. Eng.*, 1957, **64**, Sept., 152–154). A plant at U.S. Steel Corp. Duquesne works turning out low-purity gas for ferromanganese blast enrichment and high-purity gas for other uses is briefly described.

FOUNDRY PRACTICE

Modern Steel Foundry Plant on Show. (*Metallurgia*, 1957, **56**, Aug., 77–81). An account of plant shown by K. & L. Steelfounders and Engineers Ltd. on their Open Day.

Selection Chart for Investment Casting Alloys. D. V. Ludwig and R. L. Wood. (*Product Eng.*, 1956, **27**, Mid-Oct., B14–B16). For six groups of alloys this chart tabulates for each material in each group its special properties, general applications and design recommendations. Stainless steels are included.—E. A. C.

Some Questions of the Quality of Foundry Pig Iron. G. Nándori. (*Kohászati Lapok*, 1953, **8**, July, Öntöde, 154–159). The author refers to the detrimental effect of a high sulphur and cementite content in foundry pig iron, as well as the harmful influence of its fine fracture on the quality of grey iron castings. The fine fracture of the pig iron is mostly connected with FeO and H_2 content.—P. K.

Modern Techniques in Iron and Steel Foundries. T. Budinszky. (*Kohászati Lapok.*, 1952, **7**, Dec., Öntöde, 266–275). The main principles of adequate cupola construction and practice, the correct model and casting box construction, moulding technique, green sand moulding, mould and core drying and a suitable runner construction are given. The advantages and disadvantages of the basic lined cupola furnaces and of the synthetic sands are discussed. The feeding of steel castings at atmospheric and higher pressures, the exothermic heating of feeding heads and a grey iron modification method with FeSi of 75% Si content are described.—P. K.

The Present State of Development and Further Trends in Hungarian Foundries. L. Kálmán. (*Kohászati Lapok*, 1955, **10**, *Öntode*, Sept., 193–196). Reference is made to the present state of development in Hungarian foundries and further trends, especially in the use of natural and synthetic sands, core-binding materials, large green sand moulds, feeding of castings at atmospheric and higher pressures, precision and shell moulding, centrifugal and chill casting, nodular grey iron casting, gaseous malleablizing, basic-lined hot-blast cupola furnaces, reverberatory furnaces, peening with steel shot and cleaning with water jets.—P. K.

Material Standards in Iron Foundries. G. Rakovszky. (*Kohászati Lapok*, 1953, **8**, Oct., *Öntode*, 214–216). A method is given for calculating the chemical composition of grey cast iron made from raw materials of standard composition.

Scottish Works Visits. (*Foundry Trade J.*, 1957, **103**, Sept. 26, 367–375). Brief accounts of the foundries of Singer

Manufacturing Co., Alley & MacLellan, Stewarts and Lloyds, John Lang & Sons, Wm. Beardmore & Co., Robert Taylor & Co. and Babcock & Wilcox are given.

Examples of Foundry Mechanization in America. O. Carlsson. (*Gjuteriet*, 1957, **47**, (1), 1–5). [In Swedish]. Discussing systems adopted in American foundries producing small or medium size castings, the author deals with the use of continuous and semi-continuous conveyor belts, roller conveyors and bucket trucks for speeding the flow of moulds and sand.—G. G. K.

Economic Transportation in the Foundry by Means of Lifting and Stacking Trucks. F. Fink. (*Giesserei*, 1957, **44**, Apr. 25, 263–266). Transportation in the foundry by means of vehicles running on the foundry floor is discussed, particular attention being paid to lifting and stacking trucks. Examples are given of the rationalization of transportation in charging furnaces, in the preparation of sand, in moving molten iron in the melting shop, in conveying pattern and mould boxes and in the transport of finished castings. These various examples are illustrated.—R. J. W.

Pneumatic Lifting Apparatus in the Foundry. W. Gesell and W. Riege. (*Giesserei*, 1957, **44**, Mar. 28, 179–182). The properties of the electric hoist are compared with those of pneumatic lifting apparatus. The wide range of application of these pneumatic devices is illustrated in twelve simple diagrams. A pattern for cost accounting is given: this is divided into two parts, the initial and the running costs.

Selection and Application of Material Handling Equipment. J. J. Watson. (*Foundry*, 1957, **85**, Aug. 86–99). A review of shakeouts, feeders, conveyors, storage, sand mixing and premixing, and layout with notes on automation is given.

Up-to-date Cleaning of Castings. G. Szvath. (*Kohászati Lapok*, 1953, **8**, *Öntöde*, Sept., 202–204; Oct., 216–218). The author refers to the importance of satisfactory moulding and casting practice for the proper cleaning of castings. Afterwards he discusses the various cleaning equipments i.e. grinding and blasting machines, pneumatic hammers and chisels, tumbling barrels, push cores etc. Finally he deals with the health problems, methods and equipments i.e. exhaustors, ventilators, dust extractors, filters etc. in detail.

The Organisation and Practice of Maintenance in Hungarian Foundries. S. Hargitay & B. Lingsch. (*Kohászati Lapok*, 1953, **8**, *Öntöde*, July 160–163; Aug. 174–178). Organization and maintenance practice in Hungarian foundries are discussed in detail.—P. K.

Operation and Maintenance of Ventilation Equipment. A. Gustafson. (*Gjuteriet*, 1957, **47**, (1), 6–8). [In Swedish]. Practical advice is given concerning the requisite number of air changes, use of automatic temperature control devices and planned preventive maintenance. The ventilation system employed at the Norrahammar melting and moulding shops is illustrated.—G. G. K.

Accident Prevention and Hygiene in Foundries. S. Biro. (*Kohászati Lapok*, 1953, **8**, Aug., 170–174). The author discusses accident prevention and hygiene in foundries, especially in view of silicosis, gases, radiant heat, light effects, chemical attack, eye injuries and burns.—P. K.

VACUUM METALLURGY

High-Vacuum Pumping using the Roots Principle. H.-G. Nöller and R. Thees. (*V.d.I.Z.*, 1957, **99**, May 11, 613–619). A detailed description is given of the construction and operating data for pumps of the Roots type capable of producing a vacuum of 10^{-5} mm. Hg. A new application to the outgassing of steel produced by O.H. or electric furnaces is described. The steel is teemed from the ladle into moulds enclosed in a chamber continuously evacuated by a Roots pump system passing up to 10,000 m³/h.—J. B. P.

Vacuum Melting of Steels Improves Engineering Properties. H. C. Rezeau jun. (*S.A.E.J.*, 1957, **65**, Sept., 67–71). Bearing, valve and stainless and low-alloy steels are considered. The article is an abridgment of a report of a panel on "Vacuum-Melted Metals."

REHEATING FURNACES AND SOAKING PITS

Automatic Regulation of Thermal Conditions in Regenerative Pits. N. S. Skorik and N. S. Lavinchuk. (*Stal'*, (12), 1106–1110). [In Russian]. Automatic regenerator-valve reversal and the control of combustion, thermal load and working space pressure for blast furnace-gas-fired soaking pits is described; the equipment and arrangements for automatic adjustment being considered.—S. K.

The Reheating of Ingots in Electrically Heated Soaking Pits. W. Poensgen. (*Berg- u. Hüttenmänn. Monatsh.*, 1957, **102**, April, 66–76). The author reviews various design principles of electrically heated soaking pits. He deals in particular with the heating elements, heat losses, scaling of ingots, and repairs, and compares electric heating with gas and oil firing. He concludes with economic aspects, particularly those of heating high-quality steel.—T. G.

The Thermo Furnace. E. Dubois. (*Iron Coal Trades Rev.*, 1957, **175**, Sept. 20, 677–681). An illustrated account of a reheating furnace system with atmosphere control of continuous multi-zone pusher type. They are coke-oven or blast furnace gas fired and of double-parabolic cross section.

Experience in the Operation of Control and Automation Instruments on the Furnaces of a Wheel Rolling Shop. L. G. Gruberman and A. M. Andreev. (*Stal'*, 1956, (12), 1103–1105). [In Russian]. Details are given of the wheel-shop furnaces at Novo-Tagil' and of their instrumentation and control arrangements. Various advantageous modifications are described.—S. K.

Classification of Electric Furnaces and Heaters According to Method of Heating and Construction. U. Aschmann and H. Masukowitz. (*Electrowärme*, 1957, **15**, Jan.-Feb., 6–10). The results of work on classification are reported with extensive tables of method of heat transmission and their uses in furnace and heater design and of the emissivity of heaters in kw/m². Also a curve of frequency ranges is shown and their uses.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

One-Man Furnace Does Five Heat Treating Jobs. H. W. Bassett. (*Iron Age*, 1957, **180**, Aug. 22, 106–107). The one furnace used for atmosphere annealing, straight hardening case and through-carburizing and carbo-nitriding all the work in a plant producing manicure tools is described.

Small Capacity Furnaces for Heat Treatment. J.-G. Robin. (*Mét. Constr. Mécan.*, 1957, **89**, May, 467–471). A short illustrated account of typical furnaces for this type of work is presented.—B. G. B.

Mains-frequency Coreless Induction Furnaces. (*Beama J.*, 1957, **64**, Aug., 116–117). An account of the Birlec furnace at International Combustion Ltd., Derby, is given.

Resistance Furnaces for Heat Treatment in Protective Atmospheres. G. Simon. (*Elektrowärme*, 1957, **15**, Mar., 111–116). A review of furnaces using H_2, dissociated or burnt NH_3, burnt town's gas or bottled propane or CO_2 for nitriding or carburizing is given. Processes are compared and furnace designs are shown.

Methods of Controlling Atmospheres in Furnaces. O. E. Cullen. (*Steel Processing*, 1957, **43**, Aug., 458–461, 470–471; *Indust. Heating*, 1957, **24**, Aug., 1510–1512, 1514, 1519–1522, 1534). Principles and problems are discussed, including sampling. Carbon control in heat treatment is considered according to type of furnace and continuous furnaces with zoned dew point control are specially treated.

Prevention of Decarburization during High Temperature Heating of Steel. H. I. Aaronson, N. A. Gjostein, H. W. Paxton and R. W. Heckel. (*Rev. Sci. Instruments*, 1957, **28**, July, 579–580). Salt bath arrangements for heating specimens at high temperature and then transferring them to another furnace at a lower temperature are described.

Tool Steels. I. Basic Concepts Governing Their Treatment. L. F. Spencer. (*Steel Processing*, 1957, **43**, May, 253–259, 286). Fundamental characteristics, hardenability, distortion (and tests and predictions), cracking, overheating and decarburization are outlined. Procedures are then considered, forging, normalizing, annealing, hardening, quenching, tempering, special treatments such as martempering, and treatment of AISI–SAE types are briefly reviewed. Auxiliary operations are then described, grinding, removal of decarburized layers, machining and die design. **II. Why Do Tool Steels Fail?** (June, 315–323, 346). Failure owing to bad design, poor quality, incorrect heat treatment, and operational procedures are described and illustrated with notes on weld repair. **III. Selection of Tool Materials for Cold Working Operations.** (July, 372–379, 402). Steels suitable for shearing and bending

and those required for plastic deformation by tensile movement and pressing are discussed. Properties and uses are indicated with tables of compositions and heat-treatments. **IV. Selection of Materials for Hot Works Applications.** (Aug., 447–455, 469, 472). Die-casting, forging and extrusion are reviewed. Properties required are discussed and compositions and properties, effects of nitriding, hardness and uses are tabulated for die steels suitable for casting and forging and for extrusion die construction. (10 references).

Gas Carburizing. E. Fabo and G. Schön. (*Kohászati Lapok*, 1952, **7**, May, 106–116). The chemical processes of gas carburizing are discussed in detail. The composition of gases used are specified and various types of furnaces described. Hungarian experiments with a carbon steel of about 0·15% C and 8 mm dia. are reported. The advantages of gas carburizing, such as with 30–50% shorter carburizing time than by box carburizing, uniform case thickness, control of carbon content in the case, clearness and lower costs are considered.

Controlled Atmosphere Heat-Treatment of Metals. (*Tecn. Indust.*, 1956, **34**, Nov., 1635–1638). [In Spanish]. Brown-Boveri type charcoal gas generators for making protective atmospheres with up to 20%, or 35% CO are described.—P. S.

Heat Treatment Allowing Auto-Lubrication. J. L. San Juan Rubio. (*Anal. Mec. Elect.*, 1957, **34**, Mar.-Apr., 86–94). [In Spanish]. The advantages of sulphinizing are discussed, and a table of the comparative lives of various industrial components before and after this treatment, is given. When harder surfaces are required, these can be produced, without harm to the sulphinized layer, by high-frequency treatment: various machines for doing this are illustrated. Nitro-sulphinizing is another method that can be used.—P. S.

Flame Hardening, A Means for Increasing Production Efficiency. J. Püschel. (*Schweissen u. Schneiden*, 1957, **9**, June, 279–280). The economic advantages obtained by the use of flame hardening are outlined. Examples are given of flame hardened couplings and gear teeth.—U. E.

High Pressure Jet Burners. (*Metallurgia*, 1957, **56**, Sept., 125–128). A burner discharging products at 1750–1850° C at supersonic velocities is described, and its application to metal heat treatment is noted.

Scientific and Technical Conference on the Automatic Hard-Facing of Mill Rolls and other Items of Metallurgical Equipment. B. S. Shapiro. (*Stal'*, 1957, (8), 732–735).

Economical Hardening with New Electric Furnaces. T. Türk. (*Elektrowärme*, 1957, **15**, July, 260–268). Controlled atmosphere and automatic continuous furnaces are replacing the older types. The generation of atmospheres for carburizing and hardening is discussed and pot and push-through carburizing and carbonitriding furnaces are described, with details of their construction and use. Tempering furnaces are also considered.

The Importance of Surface Hardening and Internal Stresses in Structural Members. H. Staudinger. (*Metalloberfläche*, 1957, **11**, June, 200–205). The influence of internal stresses produced by heat treatment and mechanical working on the properties of structural members is discussed, with reference to a number of examples. Particular attention is paid to the relation between fatigue strength and surface residual stresses. Reference is made to the danger of producing grinding cracks in surface hardened steel.—L. D. H.

High-Resistance Materials. E. Németh. (*Kohászati Lapok*, 1953, **8**, May, 116–120). The distribution rates of heat and current in direct resistance heating and securing heat equilibrium by change of cross-section are discussed. Reference is made to austenitic and ferritic conduction-resistant alloys. The resistance and composition of salt baths are also dealt with.

Inductive Surface Hardening in Production. K. Kegal. (*Elektrowärme*, 1957, **15**, Mar., 103–107). A review with descriptions of automatic and semi-automatic installations is given. Costs as compared with other processes are considered showing savings up to 80%.

Industrial High-Frequency Heating. H. Grassmann and G. Meiners. (*Metal Treatment Drop Forging*, 1957, **24**, Sept., 358–361; *Werkstatt und Betrieb*, 1957, **4**). A review of developments, technical requirements and recent fields of application is presented.

Improvement of Quality and Rationalization by the Use of Electric Heating in Berlin Industries. M. Oppert. (*Elektrowärme*, 1957, **15**, Mar., 79–91). A general illustrated review. Razor blade hardening and other operations are referred to.

Study of the Scaling of Billets. J. Moreau and M. Cagnet. (*Rev. Mét.*, 1957, **54**, May, 383–403). Samples of scale and base metal taken from billets of three different qualities of mild steel and one semi-hard quality have been examined. The structure and composition of the various scales varied very slightly and are similar to those taken from ingots. The differences are principally total thickness, proportion of various phases, porosity and adhesion. A subscale formation appeared under the detached scale and was particularly marked in semi-hard steel and was associated with a significant decarburization of the base metal. Tests were also carried out in the laboratory to reproduce the phenomena observed in practice.—B. C. B.

Increased Productivity and Improved Performance of Continuous Heating Furnaces. E. V. En'kov, M. A. Sykulev and A. N. Pekker. (*Stal'*, 1957, (8), 755–757).

Effect of Prior Anneal Temperatures on 18/8 Wires. S. Storchheim. (*Wire and Wire Prod.*, 1957, **32**, June, 641–643, 710–712). Results are reported of an investigation of the prior anneal temperature on the magnetic properties of cold-drawn 18/8 stainless steel wire, the main conclusion being that the higher the temperature of the initial anneal, the less pronounced are the effects of cold work.—J. G. W.

Gaseous Annealing of Malleable Castings. E. Chapo. (*Kohászati Lapok*, 1953, **8**, *Öntöde*, Aug., 165–170; Sept., 185–189). Chemical reactions in the malleablizing process are discussed with special reference to the gaseous annealing process. The effect of the gas atmosphere on decarburation and graphitization is described. The author comments on the influence of H_2 atmosphere and manganese : sulphur ratio upon the annealing rate and reviews the different kinds of gaseous annealing furnaces e.g. the two-furnaces system. The practical advantages of gaseous annealing are briefly summarized.

Experiments on Heat Treatment of Cupola-Melted Blackheart Malleable Iron. E. Chapo. (*Kohászati Lapok*, 1953, **8**, June, *Öntöde*, 121–128). Experiments were carried out to determine the most favourable time and temperature in the annealing cycle. The mechanical properties of the blackheart malleable iron after various annealing treatments are given.

Continuous Stress-Relief of Transformer Laminations. (*Metallurgia*, 1957, **56**, Aug., 69–70). The development of suitable furnaces and a typical example installed by B.T.H. at Rugby are described.

Experience in the Use of Protective Atmospheres. S. A. Kulikovskii, A. N. Kalyukhnyi, M. M. Barg and B. Ya. Zeilikovich. (*Stal'*, 1957, (8), 740–744). Use in bell-type bright-annealing furnaces of incomplete combustion products of producer gas with an optimum CO content of 7–9% either eliminates the need for subsequent pickling or greatly shortens the time required.

The Elimination of Local Brittleness in Steel Sheet. M. V. Pridantsev and E. V. Smirnov. (*Stal'*, 1957, (8), 736–740). Local brittleness occurs in rimming steel after annealing above the upper critical point because of increased oxygen content and unfavourable oxide distribution at grain boundaries. It may be removed by annealing at 900–950° in dry H_2 or dissociated NH_3 (dew point not above $-40°$ C). This produces a marked fall in coercive force.

Influence of Stress on the Formation of Centres of Graphitization in the Annealing of White Iron. V. F. Zubarev. (*Liteĭnoe Proizvodstvo*, 1956, (8), 21–25). [In Russian]. In this article the influence of stresses due to different causes on graphitization centre formation in white iron castings is discussed. Thermal stresses are considered first, an equation for their calculation being deduced. From this equation, data on Young's modulus values at various temperatures and the tensile effect of structural changes on cementite the stresses with different cooling conditions are calculated. The influence of these stresses on the free-energy change of cementite is considered. Other effects discussed are the quenching, cold working and combined chemical and heat treatment of white iron and repeated transit through A_1.—S. K.

Treatment of Rails in Isothermal Furnaces. D. M. Rabinovich and B. S. Denezhkin. (*Stal'*, 1956, (12), 1094–1097). [In Russian]. A two-hour soaking of rails at 600 ± 20° C after cooling to 400–500° C was found to remove cracks due to the presence of H_2. An editorial note points out that soaking temperature should be raised to 650° C.—S. K.

Progress in Annealing at Velindre and Margam. (*Brit. Steelmaker*, 1957, **23**, Sept., 288–290). A review of equipment and operation with an account of protective atmospheres.

Studies on the Normalizing Heat-Treatment of Overheated, Structural Carbon Steel by Single or Repeated Electrical Impulse Heating. K. Wellinger and P. Rupp. (*Schweissen u. Schneiden*, 1957, **9**, July, 339–349). The material in or near the welding zone becomes overheated by the welding process and prone to brittle fracture. The authors studied the effect of an electrical impulse on the heat-treatment and the resulting structural changes of plain carbon steels. The steels were resistance-welded or artificially overheated. The electrical impulse should vary according to various requirements and the effect of repeated impulses was also studied. The impulses were given in the welding machine after the actual welding was completed. Repeated impulses gave better grain-refinement and improved notch-toughness than did single impulses. The results are described and discussed in detail.—T. G.

Determination of the Index of Quenching Severity (H) of a Quenching Liquid. Comparison of Experimental and Calculated Quench Penetration Curves. A. Rabey. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, (6), 1251–1281). The full results of tests carried out to study the quenching of a number of standard steels of different sizes are reported. The depth of hardness has also been calculated from the Jominy curves and the transformation curves using the Grossmann method.

Influence of Heat Treatment Conditions on the Magnetic Properties of EKh3 Steel. V. S. Kultygin, M. I. Vinograd and M. A. Lyubinskaya. (*Stal'*, 1956, (12), 1137–1138). [In Russian]. It was shown that the insufficient residual magnetic induction of EKh3 steel (0·90–1·10% C, 0·17–0·40% Si, 0·20–0·40% Mn, 2·80–3·80% Cr, $<$ 0·03% P, $<$ 0·02% S and $<$ 0·30% Ni) which was normally oil quenched could be improved by quenching in oil through water, by treatment at − 183° C or by simple storage after quenching.—S. K.

Tool Treatment Techniques. L. Sinclair. (*Australasian Eng.*, 1957, **50**, July 8, 69–74). Martempering, the *TTT* curve, quenching, straightening and the treatment of die casting dies are briefly considered.

Some Thoughts on Spring Heat-Treatment and Finishing. E. Mitchell. (*Wire Ind.*, 1957, **24**, June, 561, 564, 567–569). Austempering conditions and the effects of good and bad heat treatment are discussed, with illustrations of structure and of faults in tempering and barrel finishing. Furnaces are reviewed, batch and continuous, and protective and other atmospheres are briefly considered.

Grain Boundary Damage in a CrNiW-steel due to Overheating. J. Ogerman. (*Neue Hütte*, 1957, **2**, May, 289–299). The effect has been investigated, on fractures in a CrNiW steel, of heating temperatures ranging from 1200 to 1350° C, duration of heating, rate of cooling, degree of deformation and tempering. It was found that grain boundary damage can be prevented by overheating and subsequent cooling of the specimens. It is suggested that adsorption phenomena may be responsible for grain boundary damage.—L. J. L.

FORGING, STAMPING, DRAWING, AND PRESSING

The Trend of Developments in the Heavy Forging Industry. L. Némethy. (*Kohászati Lapok*, 1956, **11**, April, 153–165). Reference is made to the development of hydraulic forging presses, manipulators forge hammers, heating equipment, especially with oil gasification and induction.—P. K.

Up-to-date Equipment for Die Forging. A. Terény. (*Kohászati Lapok*, 1955, **10**, Sept., 386–400). The author reviews comprehensively up-to-date equipment for die forging, especially drop hammers, drop forging presses, rotating machines, dies with more impressions, hot pressed die impressions, induction or contact heating and scale-free heating in a lithium vapour atmosphere. Finally he comments on their applicability in Hungary.—P. K.

The Intermediate Stage in Drop Forging. O. Kienzle and K. Spies. (*Metal Treatment Drop Forging*, 1957, **24**, Sept., 367–374; *Werkstattstechnik und Maschinenbau*, 1957, Apr.). A discussion of correct design with many examples is given.

Mechanical Properties of Large Forgings of the Russian Steel 35XH3M. P. V. Sklujev and V. G. Gorjacsko. (*Kohászati Lapok*, 1952, **7**, Oct., 229–235). Russian heat treatment experiments with large forgings of a Cr–Ni–Mo steel (C 0·36, Cr 1, Ni 3·5, Mo 0·5%) are discussed. The results of the mechanical, metallographic and stress examination of these forgings show that a heat treatment consisting of normalizing and tempering is the most advantageous.—P. K.

Improvement in the Quality of Large Forgings by Means of Heat Treatment. Z. Bartha and P. Kövesi. (*Kohaszati Lapok*, 1952, **7**, Sept., 203–209). Typical defects in large forgings of carbon steel are described. A special heat treatment is suggested, based on Hungarian laboratory and full scale experiments, for improving the homogeneity and mechanical properties and for the elimination of H_2. This treatment consists of homogenizing at 1050° C, double normalizing, first at 900° C and then at 850° C and tempering at 620° C, followed by very slow cooling in the furnace at 100° C.—P. K.

Cooling of Alloyed Steel Forgings. P. V. Szkuljev and M. P. Braun. (*Kohászati Lapok*, 1953, **8**, Feb., 40–46). An isothermal cooling cycle is presented, based on the transformation kinetics of austenite, for elimination of flakes in large Ni–Cr steel forgings. The cycle consists of cooling at 300–350° C after forging, reheating at 650° C and afterwards cooling in the furnace or in air. The holding time at 300–350° C and 650° C depends on the dimensions of the forging.—P. K.

The Influence of Hydrogen upon the Mechanical Properties of Large Forgings. P. V. Szklujev and V. A. Mirmelstein. (*Kohászati Lapok*, 1952, **7**, Dec. 284–288; 1953, **8**, Jan. 13–16). The elongation and reduction of area of transverse specimens, taken from the inner part of large alloyed steel forgings, have been improved by ageing for about ten days, or stress-releasing at 200–650° C of the specimens or the forgings. The authors assume that this effect is due to the equalization of the concentration and partly to elimination of H_2. This assumption is verified experimentally by the decrease in elongation and reduction of area of the stress released specimens after electrolytic saturation with H_2, and the regaining of the toughness by ageing these specimens.—P. K.

Punching of Stainless Steel Using Induction Motors of Insufficient Power. V. T. Ermakov. (*Stal'*, 1957, (8), 732).

Complex Shapes at Bargain Rates. (*Steel*, 1957, **141**, Aug. 12, 124–126). Applications and advantages of hydroforming are explained. The method uses a pressure chamber sealed with a flexible diaphragm, in place of the conventional female die. It is used for producing small quantities of parts and parts difficult to make by conventional means.—D. L. C. P.

A Contribution to the Assessment of the Cold Swaging Characteristics of Tool Steels. K. Bungardt and O. Mülders. (*Arch. Eisenhüttenwesen*, 1957, **28**, July, 383–395). The results are reported of tests on 6 non-alloyed steels ranging from 0·03 to 1% C and the steels 20MnCr5, X30WCrV53, and 45 CrMoV57 with the object of finding parameters independent of shape, that could be used to assess deformation characteristics.—L. J. L.

Drawing of the Square Cross-Section Rod. H. Yamanouchi and I. Hayashi. (*Rep. Castings Res. Lab. Waseda Univ.*, 1956, Oct., 59–62). [In English]. Work is reported for annealed carbon steel drawn through square-section tool-steel dies. The hardness distribution over the cross-section is determined experimentally, and Siebel's formula for drawing force in circular dies is modified for the square case.—K. E. J.

Residual Stress is the Principal Cause of Changes of Rod Diameter after Cold Drawing. M. M. Kobrin. (*Stal'*, 1957, (81, 754–757).

Calculation of the Various Stages of Deep Drawing for a Component. R. Dupas. (*Mét. Constr. Mécan.*, 1957, **89**, May, 431–435). A practical description is given of the method of calculating the required stages of deep drawing for a typical component.—B. G. B.

Multiple Cold Drawing of Tubes with the Use of Phosphatizing. M. S. Goncharevskii, F. A. Danilov, S. S. Shalkevich and P. K. Stasevich. (*Stal'*, 1957, (3), 243–253). [In Russian]. Laboratory and full scale work on the use of phosphatizing to improve the multiple cold drawing of tubes is described and information on the corresponding changes in mechanical properties and microstructures is given. Phosphatizing bath composition and the lubrication of phosphatized tubes are also dealt with. The use of the technique developed enables normal double drawing of tubes to be effected on a short mandrel without intermediate annealing and with total deformations up to 60%. At the Novotrubnyi works the introduction of the technique has resulted in increased productivity and decreased costs, fuel, tool and metal consumptions. Other advantages of the method and additional research work required are also discussed.—S. K.

A Device for Catching the End of Broken Wire. Yu. N. Volkov. (*Stal'*, 1956, (12), 1135–1137). [In Russian]. The

form of the danger-zone near wire-drawing installations is discussed and a device is described which catches the end of the wire in case of breakage. In tests the device is said to have increased productivity as well as safety.—S. K.

Defects in Steel Wire. L. Mankher. (*Kohászati Lapok*, 1953, **8**, Nov., 225–239). The author discusses comprehensively the various kinds of steel wire defects originating from inadequate steelmaking, rolling or cold drawing practice, and their cause and avoidance. He stresses the importance of ingot dressing, grain size, proper heat-treatment and pickling. The steel contained C 0·3–0·9, Mn 0·3–0·7, Si 0·35 max, P 0·04 max, S 0·04 max, Cu 0·2 max, Ni 0·1 max, Cr 0·1 max.

Composition, Properties and Mechanical Strength of American Metallic Materials for Coil Springs. H. Keitel. (*Draht*, 1957, **8**, May, 180–186). Carbon steels, alloy steels, Cu and Ni alloys used in the U.S.A. for the manufacture of coil springs are listed, the specifications including mechanical properties of the wire and permissible spring stresses. Data are also included on the fatigue strength and setting properties at elevated temperatures of a range of materials.—J. G. W.

Considerations Relating to the Practice of Production Management in the Steel Wire Industry. C. Coates. (*Wire Ind.*, 1957, **24**, Aug., 727–729, 731–732, 760). A Staff School Award paper.

Extruded Shapes and Specials Cut Costs. G. H. De Groat. (*Metalworking Prod.*, 1957, **101**, Aug. 9, 1381–1383). Production of sprag contours for clutches is described.

When to Use Cold Extrusion for Steel Parts. C. B. Grace. (*Product Eng.*, 1957, **28**, Aug., 145–147). Notes on design and effects of extrusion on yield strength and elongation.

Steel Extrusions Using Glass Lubrication. (*Product Eng.*, 1956, **27**, Mid-Oct., D15–D17). The use of molten glass as a die lubricant has made the extrusion of difficult metals and shapes a practicable proposition. A short description is given of the process and its advantages are discussed.—E. A. C.

ROLLING-MILL PRACTICE

New Methods of Plastic Deformation in the Working of Metals. F. Platzer. (*Berg- u. Hüttenmänn. Monatsh.*, 1957, **102**, April, 115–125). A lecture. Reductions in area of 25–35% are usual in modern rolling mills. If higher reductions, e.g. 80% and more, could be employed, the rolling mills would be kept very much smaller and savings in production costs and capital outlay would be made. The author discusses the various principles of the high-reduction mill, such as the Pilger mill, the Krause mill, and the Sendzimir planetary mill and describes in general terms a new type of planetary mill that he calls "*Abrollwalzwerk*." The design principles of a number of modifications of this rolling mill are outlined.—T. G.

Influence of Mill Spring on Dimensions of the Rolled Stock. H. Warrol. (*Jernkontorets Ann.*, 1957, **141**, (1), 28–36), [In Swedish]. The paper deals with mill deformation when absorbing roll force and the plastic deformation of the stock. A graph illustrates equilibrium conditions prevailing between mill spring force and roll force, this facilitating calculation of the influence of various factors on stock thickness.—G. G. K.

Friction in Cold Rolling. P. Funke, jun. (*Stahl u. Eisen*, 1957, **77**, June 27, 882–884). A review of recent publications—mostly English—on friction in cold rolling.—T. G.

The Manufacture of Metallurgical Rolls from Mg-treated Cast Iron. F. Reinshagen and W. Findeisen. (*Giessereitechn.*, 1957, **3**, July, 145–151). A description is given of operating experience gained in the use of nodular graphite iron in the production of metallurgical rolls. The development of the processes used is discussed. The metallurgical principles involved in the use of Mg and its alloys are known, but industrial processes in the East German Republic still fall short of international standards.—L. J. L.

Experiments on the Production of Nodular Chilled Iron Rolls during 1952. B. Körös. (*Kohászati Lapok*, 1953, **8**, *Öntöde*, April 73–82; May 97–103). Three series of experiments were carried out with Mg treatment to increase the wear resistance and the strength of the core of chilled rolls. Small rolls up to 1·5 t and sheet rolls up to 6·5 t were treated: (1) with a Mg–FeSi–Cu alloy, (2) with the alloy in (1) + Elektron, (3) with Elektron only. Nodular iron with pearlitic structure and high wear resistance has been consistently obtained. The tensile strength of the wobblers was between 23·5–27 t.s.i. The experiments will be continued with other types of rolls.

Straightening Track on Roller-Straightening Machines. S. V. Gubert and O. P. Gurfinkel'. (*Stal'*, 1956, (12), 1133–1134). [In Russian]. The use of an 8-roller straightening machine for correcting the curvature acquired during cooling by the asymmetric rolled strip used for making tractor tracks is described.—S. K.

Translator Control. W. N. Jenkins. (*J. Iron Steel Inst.*, 1958, Feb., **188**, 157–167). [This issue].

The Effect of Rolling on the Susceptibility of Deep-Drawing Steel Sheet to Tearing. B. Otta and J. Teindl. (*Hutnické Listy*, 1957, **12**, (6), 515–517). [In Czech]. On the basis of an investigation of the factors involved in the production of thin steel sheet it is shown that, apart from impurities, composition, dimensional heterogeneities etc. treated earlier, there is also a noticeable influence on the deep-drawability of interpass annealing schedules and reductions per pass. Two intermediate annealings are better than just one; similarly 5 or 6 passes to reach a given reduction were found superior to the use of only 4. The steel was of the 0·08% C plain type, with 0·02% S and 0·02% P.—P. F.

Radiological Thickness Gauging in Hot Rolling. H. Warrol and B. Wahlberg. (*Jernkontorets Ann.*, 1956, **140**, (12), 907–929). [In Swedish]. A committee set up by Jernkontoret reports on the principles and application of thickness gauging by radiation. The influence of radiation intensity and detector design on accuracy and time lag is discussed. X-Ray and isotope methods were investigated. Details are given of results obtained with a 75 kV X-ray generator unit equipped with an automatic calibration device and of possible applications of continuous gauging methods.—G. G. K.

MACHINERY FOR IRON AND STEEL WORKS

Jointless Rail Tracks on Monolithic Flooring for Metallurgical Works. I. P. Grave, M. P. Smirnov, V. F. Yakovlev and N. M. Prokop'ev. (*Stal'*, 1957, (8), 762–764).

Hydraulic Equipment in Steelworks. IV. Modern Pumps and Motors. F. B. Levetus. (*Iron Coal Trades Rev.*, 1957, **175**, Aug. 30, 494–496). Gear, vane and piston units and drives are briefly reviewed with notes on control.

Handling Cold-Finished Bars with Woven Wire Slings. J. C. Applegarth. (*Steel Processing*, 1957, **43**, Aug., 456–457). Loads up to 7500 lb are handled without damage to the edges.

Signalling Equipment in Steel Works for Controlling Materials Flow. H. E. von König. (*Stahl u. Eisen*, 1957, **77**, Aug. 8, 1081–1089). Signalling equipment for controlling and supervising the flow of the materials in a combined steel works and rolling mill is described and illustrated. The use of teleprinters and television by closed circuit are included. This system is regarded as a step towards automation.—T. G.

Distribution of Compressed Air. Lefevre. (*Usine Nouvelle*, 1957, July, 29, 31–32). A review of apparatus, valves, purifiers etc. and of points to note in the installation and operation of compressed air systems is given.

Improvement in the Air-Supply and Pneumatic-Equipment Control Systems. V. S. Artyukh. (*Stal'*, 1956, (12), 1116–1121). [In Russian]. A critical survey is made of systems at present used at Soviet metallurgical works for supplying and using compressed air and the modernization of equipment which have led to a reduction of electricity consumption for compression at a tube works. The installation of a dual supply, 7·5 and at 4 atm. (gauge) was found to be advantageous.

WELDING AND FLAME CUTTING

25 Years of Welding Research and Development. F. Rapatz. (*Schweisstechnik*, 1957, **11**, June, 61–65). The author gives a survey of welding research and development work carried out over the last 25 years. Particular reference is made to the work carried out by Böhler Co. Ltd. who prevented hot-tears by Mn additions.—R. F.

Jet Burner Heating. (*Iron Coal Trades Rev.*, 1957, **175**, Aug. 30, 497–501). A new design by the N.E. Gas Board has been used for the production of lap-welded steel tubes. Burner construction is shown and the advantages of supersonic operation given.

Welding Phenomena between Solid Steel and Molten Cast Iron. T. Muraki. (*Rep. Castings Res. Lab. Waseda Univ.*, 1956, Oct., 87–90). [In English]. Experiments with cast iron

and mild steel heated in an argon atmosphere without pressure at temperatures between 950° and 1150° C are described. A theoretical explanation of the results confirms that welding is a diffusion phenomenon; the activation energy of diffusion (mainly carbon atoms) therefore mainly determines ease of welding in different combinations.—K. E. J.

The 18–4–1 Cobalt Type High Speed Steels. Some Metallurgical Problems of Their Flash Welding to a Carbon Steel. F. A. Calvo Calvo. (*Cien. Tecn. Solda.*, 1957, Mar.-Apr. 6, pp. 12). [In Spanish]. Defects that can arise when flash welding an 18–4–1 type steel, contining 5% Co, to a carbon steel shank (0·5–0·6% C, 0·25–0·40% Mn, 0·10–0·25% Si) have been studied and the following conclusions drawn:— (i) the high speed steel must be of good quality, any manufacturing defect will make welding more difficult, (ii) if the arc operates at a low intensity for too long a time, deep decarburization occurs in the carbon steel and there is eutectic formation in the high speed steel: the former reduces fatigue resistance, the latter causes brittleness, (iii) the eutectic zones can decompose to form graphite making the weld useless, (iv) the presence of detached grains of the carbon steel, dissolved in the high speed steel, causes lamellar eutectic formation and gives rise to micro-cracks, (v) control of the current intensity, the time of discharge of the arc, the separation of the parts, the pressure of the weld and the velocity of cooling will prevent the development of these defects in a harmful form.

Welding of Stainless Steels. H. Thielsch. (*Product Eng.*, 1956, **27**, Mid-Oct., D7–D9). A table is given showing the alloying elements to be added to give particular properties to stainless steels. Points to be observed for the satisfactory welding of austenitic and martensitic steels are discussed and a table is included giving the characteristics of various stainless steel electrodes.—E. A. C.

Resistance Welding of Stainless Steel. (*Aciers Fins Spec. Franç.*, 1957, July, 54–68; In English 58–61). A review of the various processes and of the special requirements of stainless steel is given. Spot, projection, roller spot, and resistance and flash butt welding are treated.

Welding Characteristics of Hard and Alloy Steels. E. Henrion. (*Prat. Soud.*, 1956., **10**, Nov., 183–188; **10**, Dec., 206–209; 1957, **11**, Jan., 9–14). [In French]. The author makes a detailed review of current theory and practice of the welding of high carbon and alloy steels. The latest techniques are discussed and numerous examples are given illustrating major works where welding has shown technical and economic advantages.—M. D. J. B.

On the Weldability of Alloy Steels Insensitive to the Effect of Hydrogen. K. Mazanec and K. Pawera. (*Zváranie*, 1957, **6**, (5), 131–136). [In Czech]. An electrode was developed for use with special chromium steels as utilized in high-temperature hydrogenation plant. The nominal composition of the metal and of the electrode is 0·22% C, 0·49% Mn, 0·37% Si, 0·013% P, 0·014% S, 0·10% Ni, 3·13% Cr, 0·25% Mo and 0·47% V. Welding technology, heat-treatments, mechanical tests and metallurgical aspects of welding seamless tubes with the electrode are discussed, and optimum conditions are stated. The results obtained were entirely satisfactory.—P. F.

Transition between Austenitic Welding Material and Unalloyed Steel. E. Rubo. (*Metall*, 1957, **11**, May, 388–391). Previous knowledge concerning the structure and properties of welds in un-alloyed steels made with austenitic electrodes is summarized. There follows an account of the author's investigation of the fatigue limit of mild steel plate welded with an 18/8 type austenitic steel electrode. The structure of the transition region between weld and parent metal was also examined. The high notch sensitivity of the transition zone is explained in terms of the substantial difference of electric modulus as between the weld and the parent metal.—J. G. W.

Progress in Welds with Austenitic Materials in the Construction of Apparatus and Containers. J. Mundt. (*Techn. Mitt. Krupp*, 1957, **15**, June, 29–36). Problems associated with the welding of alloy and plated steels are discussed, and illustrated by three examples. A table is appended showing the correct preparation and techniques to give trouble-free operation.

Preparation of Parts for Welding. M. Leruth. (*Prat. Soud.*, 1957, **11**, Jan., 1–7). [In French]. The author discusses the preparation of parts to be welded and the sizes of electrodes to use in order to get the best practical results.—M. D. J. B.

Applicability of Clad Steels to Heavy Wall Piping. J. H. Proctor. (*Amer. Soc. Mech. Eng., 2nd Nuclear Eng. and Sci. Conference*, 1957, 57-NESC-108, pp. 7). Temperature and pressure conditions, welding and fabrication are considered.

The Metallurgy of the Welding of Heat-Resistant Chromium–Molybdenum and Chromium–Nickel Steels. E. Kauhausen. (*Dansk Tekn. Tidsskr.*, 1957, **81**, May, 111–116). [In German]. A lecture given to the Dansk Svejseteknisk Landsforening on March 22, 1957. The author discusses the types of heat-resistant steels of the Cr–Mo and Cr–Ni group that are suitable for welding by various methods including oxy-acetylene Argonarc and Sigma welding. He deals in detail with heat-treatment before and after welding and the various types of defect resulting from contamination by atmospheric gases and from unsuitable heat-treatment, in particular with microcracks which are difficult to detect.—T. G.

Modern Welded Constructions for Conveyor Equipment. H. Bückreiss and T. Schaaf. (*Schweissen u. Schneiden*, 1957, **9**, June, 257–260). Conveyor equipment of welded construction is described. Features such as weight, maintenance, architectural appearance and costs are discussed.—U. E.

Studies of Upset Variables in the Flash Welding of Steels. E. F. Nippes, W. F. Savage, G. Grotke and S. M. Robelotto. (*Welding J.*, 1957, **36**, Apr., 192s–216s). Flash welds were made in AISI 1020, 4130 and 4340 steels with two rates of platen acceleration and controlled amounts of upset current. The effects of temp. gradient, upset current density and composition were determined. The welds were bend tested and significant differences were found. An etching technique for flat spots was developed and an hypothesis for their formation was developed. High-speed cinephotography was used to investigate flashing and oscillograms of primary and secondary voltage and primary current during flashing are shown.

Welding under Flux of Thick Walled Boiler Chambers with Semiautomatic Equipment. PSh-5. I. D. Davydenko and G. G. Gorodetskii. (*Avtom. Svarka*, 1951, **4**, (5) [20], 69–72). [In Russian]. Welding technique of walls of boilers 25–50 mm thick using the above equipment is described.—V. G.

The Use of Spot Welding of Angle Joints in the Shipbuilding Industry. N. M. Nikitinykh and P. A. Alsuf'ev. (*Avtom. Svarka*, 1951, **4**, (5) [20], 60–65). [In Russian]. Results obtained in introducing spot welding under flux of angle joints with semiautomatic equipment are given.—V. G.

Automatic Welding of Fire Tubes for Locomotive Boilers. V. A. Chumachenko, V. P. Stepenko and B. I. Deniskin. (*Avtom. Svarka*, 1951, **4**, (3) [18], 67–70). [In Russian]. Equipment and technology for the automatic welding under flux of locomotive boiler tubes are described.—V. G.

Welding Pins to Screening Boiler Tubes by Electrical Resistance Contact Welding. N. G. Ostapenko and G. V. Gorbunov. (*Avtom. Svarka*, 1951, **4**, (4) [19], 85–89). [In Russian]. Advantages of contact welding of the above parts instead of arc welding as used at present, are demonstrated.

The Influence of Cooling Velocity on the Structure and Mechanical Properties of an Automatically Welded Seam in Low-Carbon Steel. S. A. Ostrovskaya. (*Avtom. Svarka*, 1951, **4**, (4) [19], 9–31). [In Russian]. Data characterizing the dependence of charges in the structure and mechanical properties of an automatically welded seam on the thickness of metal, welding practice and the initial temperature of the article welded are given. It was shown that an increase in the velocity of cooling leads to a change in the eutectiod structure, an increase in the tensile strength and yield point and a decrease in the relative elongation and necking. Measures which should secure the necessary quality of the welding of metal of 30–50 mm thick are proposed.—V. G.

The Design of Joining of Longitudinal and Transverse Beams in Totally Welded Bridges with Bottom Drive. V. V. Shvernitskii and V. I. Trufyakov. (*Avtom. Svarka*, 1951, **4**, (4) [19], 56–72). [In Russian]. Design for joining the above is discussed. On the basis of static strength and the ease of fabrication, some definite designs are proposed. Results of vibrational tests of the above construction are given.—V. G.

Power Measurements in Contact Welding. V. K. Lebedev and Yu. D. Gupalo. (*Avtom. Svarka*, 1951, **4**, (4) [19], 90–92). [In Russian]. A simple and reliable method of measuring power consumption by contact welding equipment using an ordinary single phase meter is described.—V. G.

Ultra-High-Strength Weld Metal with Low Hydrogen Electrodes. D. C. Smith. (*Welding Res. Council Bull.*, No. 36, May, 1957, pp. 14). The development of ultra-high-strength steels is reviewed. Six different types of weld metal are proposed and their physical properties investigated. Their

weldability was found to be similar and typical of low hydrogen iron powder types with a globular metal arc transfer.

Welding Speed and Efficiency of Iron-Powder Coated Electrodes. J. ter Berg. (*Brit. Welding J.*, 1957, **4**, June, 253–256). Formulæ are developed for high deposition speeds and high energy efficiencies and compared with experimental results.

Flux AN-348-A. D. M. Rabkin. (*Avtom. Svarka*, 1951, **4**, (19), 32–43). [In Russian]. Theoretical and experimental bases for the development of the flux AN-348-A for automatic and semi-automatic welding of low-carbon steel are described. Chemical composition of the flux is given.—V. G.

A Method of Granulating Flux Without Preliminary Grinding. V. E. Dondik. (*Avtom. Svarka*, 1951, **4**, (5) [20], 73–77). [In Russian]. Molten flux is sprayed by compressed air. The length of travel through air of flux droplets is so chosen that they are completely cooled. Good quality flux free from dust, but with somewhat increased sensitivity to rust, is produced.—V. G.

An Increase in Plasticity and a Decrease in Sensitivity to Stress Concentration of Welded Joints in Low-Alloy Steel. B. S. Kasatkin. (*Avtom. Svarka*, 1951, **4**, (3) [18], 3–21). [In Russian]. It was experimentally shown that under static load thick welded joints from low alloy steel show a decrease in plasticity and an increase in sensitivity to stress concentrations. By a localized thermal treatment of the welded seam and places of stress concentration with an acetylene torch, a considerable increase of plasticity and a decrease in sensitivity to stress concentrations can be obtained.—V. G.

Impulse-Magnetic Running Gear for Welding Equipment. V. E. Paton. (*Avtom. Svarka*, 1951, **4**, (4) [19], 82–84). [In Russian]. The purpose, operating principles and advantages of a new system of running gear for welding equipment are discussed.—V. G.

Control of the Process of Spot Welding by Controlling the Shift of Electrodes of a Welding Machine. Yu. A. Pachentsev. (*Avtom. Svarka*, 1951, **4**, (5) [20], 18–29). [In Russian]. A new method of automatic control of the spot welding process is described. Some experimental data supporting the advantages of this method are given.—V. G.

Control of the Tightness of Welds of Bottoms of Cylindrical Reservoirs Welded Directly on a Sand Base. A. S. Fal'kevich and I. E. Neifel'd. (*Avtom. Svarka*, 1951, **4**, (5) [20], 66–68). [In Russian]. The use of ammonia gas and a phenolphthalein solution for the detection of leaks in joints is recommended.

On Methods of Testing Welded Joints from Acid-Resistant Steel for Intercrystalline Corrosion. B. I. Medovar and N. A. Langer. (*Avtom. Svarka*, 1951, **4**, (5) [20], 37–42). [In Russian]. A rapid method of testing is described. The use of a mixture of 10% HNO_3 + 2% NaF as a reagent is recommended.

On the Deformation of Sheets during Automatic Welding of Panels. B. M. Shinkarev. (*Avtom. Svarka*, 1951, **4**, (5) [20], 78–87). [In Russian]. The problem of changes in clearance and width of the welded seam in the plane of sheets during their contact welding with automatic equipment is discussed. Some measures preventing the turning of sheets are proposed.

Factors Affecting the Tensile Properties of Steel Weld Metal. C. M. Wayman and R. D. Stout. (*Welding J.*, 1957, **36**, May, 252s–264s). Structural defects and their elimination, alloying elements, C, N, O, H, S, and P are all considered. Bare metal composition has little effect. Welding rods, techniques and variables are reviewed and stresses, cooling rates and preheat, post-welding heat-treatment and criteria for evaluation are then summarized. (59 references).

Notch-Toughness Characteristics of Submerged-Arc Weld Deposits. I. L. Stern, N. A. Kahn and H. Nagler. (*Welding J.*, 1957, **36**, May, 226s–234s). Wide variations for a given steel were found, but values are reproducible for a given procedure and weld-deposit composition. Tear tests and notch-toughness values of base metal and weld are shown. Weld metal composition can have a marked effect on transition properties, no general rule can be made for layer thickness and transition properties and layer thicknesses not over $\frac{1}{2}$ in. will often give poor notch-toughness properties.

Structure of Weld Metal Examined by Autoradiography. B. I. Bruk. (*Svarochnoe Proizvodstvo*, 1955, (11), 8–13). It was found that S distribution is uniform in general but in regions remote from the core of the weld there is dendritic segregation, the S concentrating in the interspaces. Stratification of weld metal is disclosed connected with S distribution, close to the basis metal in large welds and throughout small welds. An explanation is advanced.

Vibrational Strength of Welded Joints from Low Alloy and Low Carbon Steels under Symmetrical and Pulsating Stress Cycles. A. E. Asnis. (*Avtom. Svarka*, 1951, **4**, (5) [20], 3–17). [In Russian]. The problem of utilizing low alloy steels of increased strength instead of low carbon steel for welded joints operating under vibrational load is discussed. From experimental evidence it is concluded that the application of low alloy steels for this purpose is not advantageous as the strength of welded joints from both kinds of steel is practically the same. Some data on testing joints from a low alloy steel of a new kind superior to those used at present are given.—V. G.

The Problem of Embrittlement in the Welding of Austenitic Heat-resisting Steels. H. F. Tremlett. (*Brit. Welding J.*, 1957, **4**, June, 283–287). Sigma-phase formation tends to occur from duplex and fully austenitic welds at 900°. Degree of embrittlement is related to the amount of carbide plus σ-phase and may be calculated from composition. Si is harmful and preferred compositions for steel and weld are given. Hot-crack susceptibility of non-embrittling weld metal can be mitigated by suggestions given.

How To Cut Down on Weld Metal Cracking. (*Iron Age*, 1957, **179**, Jan. 24, 83). Hot-cracking can be minimized by: attention to steel compositions (C < 0·25%, S and P < 0·02%); attention to design of weld; use of high-Mn electrodes; and by controlled cooling.—D. L. C. P.

Influence of Welding in the Design of Steel Works Plant. O. Wilmes. (*Schweissen u. Schneiden*, 1957, **9**, June, 284–286). The application of welding to converters, gear boxes and rolling mill plant is described with illustrations.—U. E.

The Effect of Welding Technique on the Manufacture of Heavy Machinery and Presses. H. Ginzler. (*Schweissen u. Schneiden*, 1957, **9**, June, 286–289). Brief discussions of welded heavy machinery and presses and their economics are given.—U. E.

Automatic Welding of Alloy Steels in Equipment for Chemical Industry. H. Dahms. (*Schweissen u. Schneiden*, 1957, **9**, June, 295–296). The properties and weldability of alloy steels are briefly discussed.—U. E.

Special Welding Methods in the Manufacture of Alloy Steel Sheet. W. Liebig. (*Schweissen u. Schneiden*, 1957, **9**, June, 297–298). The welding of blades used in wind tunnels is described.—U. E.

Some Factors which Can Influence the Quality of Pure Welding Material. H. Sachs. (*Techn. Mitt. Krupp*, 1957, **15**, June, 37–46). The properties of arc welds made from 4 types of electrode were investigated systematically. The weld material was built up under standard conditions, and the influence of the average temperature during layering, the method of applying the electrode, subsequent heat treatment of the weld material and its H_2 content on the physical properties and structure of the material were studied.—L. D. H.

Welding Solves Down Time Problem. P. H. Lessard and W. E. Heestand. (*Steel*, 1957, **141**, Aug. 12, 144–147). An account is given of the repair of a broken part in a large manipulator, which, taking 28 days, saved 45 days compared with waiting for a replacement. The broken flange of the 7·7 ton peel was welded and stress relieved.—D. L. C. P.

Welding and Destructive Testing. W. Raabe. (*Schweissen u. Schneiden*, 1957, **9**, June, 337–338). A brief discussion of destructive test methods and equipment for them is given.

The Use of Surface Colours due to Hot Oxidation as a Non-destructive Method of Testing Spot Welds. P. Journat. (*Soudage et Techniques Connexes*, 1957, **11**, March-April, 93–99). The method is used to determine the efficiency of heat treatment under electrode tips without destroying the welds. The relationship between colorations, hardness and stress in spot welds is discussed. The method aids setting and enables checks on settings to be made during manufacture. The area of the coloured zone is found to depend chiefly on the current intensity and welding time.—R. P.

Non-destructive Macro Testing of Annealed Steel Welds. H. Granjon. (*Soudage et Techniques Connexes*, 1957, **11**, May-June, 189–193). A method for macro-etching the surface of fusion-welded joints is discussed. The heat treatment of the weld can be checked by this means. The method is compared with macro- and micro-examinations.—R. P.

Brazing Alloys with Lithium Additions. N. Bredzs and D. Canonico. (*Product Eng.*, 1956, **27**, Mid-Oct., G2–G6). The brazing of alloys with fluxes or in a reducing atmosphere is

discussed briefly, and the need for deoxidizing metal additions for self-fluxing brazing alloys is emphasized. A description is given of experiments carried out to determine if Li is a suitable addition and the results and conclusions reached are reported.—E. A. C.

Tests for the Determination of the Steeping Temperature on Brazed Steel. M. Evrard. (*Cuivre, Laitons, Alliages*, 1956, **33**, Sept./Oct., 41–45). The steeping temperature was measured by means of a thermo-couple, using standard test bars. Time-temperature curves were plotted. Under experimental conditions, the steeping temperature was below the melting point of the brazing metal.—R. P.

Steel Sandwich Structure to Highlight New Fighter Aircraft. A. F. Ensrud. (*S.A.E.J.*, 1957, **65**, Aug., 38–42). A discussion of joining methods for 300 and 400 series stainless steels.

Soldering for Joining Stainless Steels. P. C. Ziemke. (*Chem. Eng.*, 1957, **64**, Aug., 292). Silver soldering is described. Conditions are chosen to minimize carbide precipitation.

Experimental Bonding of Titanium and Stainless Steel. (*Machinery*, 1957, **91**, Aug. 23, 419). Experimental work by Boeing Airplane Co is briefly reported.

Bibliography of Adhesives for Metals and Metal Bonding. (*Technik*, 1957, **9**, Sept., 647).

Cutting of Steel Plates by Means of Munroe Effect. S. Yamamoto. (*Tokyo University, Annual Report of the Engineering Research Institute*, 1957, **15**, No. 2, March, 107–110). An empirical relation between weight of explosive charge and cutting area is obtained. RDX (39%), TNT (60%) and graphite (1%) was used.

MACHINING AND MACHINABILITY

Lead in Cast Steel: How Much Does Machinability Improve? W. J. Phillips and D. B. Barron. (*Iron Age*, 1957, **180**, Aug. 15, 102–103). Reference is made to the development of a method for the distribution of lead in melts of steel for casting. Results of tests, and production experience are given in showing the improvements in machinability possible with leaded cast steels.—D. L. C. P.

Add Copper To Make Steel Bars More Machinable. (*Iron Age*, 1957, **180**, Aug. 22, 112–114). Properties of cold drawn steel bars with controlled Cu additions made to the alloy are described. As well as 10% increase in machinability, improvements in the following are claimed:— corrosion-resistance, wear properties, overall strength and resistance to warping.—D. L. C. P.

Machining Heat-Resistant Alloys. R. D. Halverstadt. (*Machine Design*, 1957, **29**, June 13, 163–168). Stainless steels are included. The article refers to improved designs for easier machining.

Control of Quality and Efficiency of Hard Metal Tools. M. Angel Muro. (*Tecn. Met.*, 1955, **11**, Sept.-Oct., 173–178). [In Spanish]. The cutting efficiency of two types of sintered carbide tools has been examined for correlation with their microstructures. The first type, made from ~ 6% Co and 94% WC, gave the best results with a fine grain size and uniform structure. The second type, of 9% Co, 15% TiC and 76% WC, gave similar results. It is suggested that microscopical examination, in conjunction with specific gravity and hardness tests, provides a satisfactory control of quality and illustrations in support of this view are given.—P. S.

Longer Tool Life and Economy by Building Up Tool Tips by Welding. K. Schmidt. (*Schweissen u. Schneiden*, 1957, **9**, June, 277–278). The materials used for hard facing are: WC powder, Cr–Mn alloys, with bits of cast or sintered carbides. Some examples are given.—U. E.

The Determination of Cross Flow as an Aid in Calibrating Profile Tool Steel. H. Neumann and W. Lehmann. (*Neue Hütte*, 1957, **2**, May, 307–317). The calculation of cross flow in limited flattening; cross flow in T- and U-sections; the application of cross flow calculations to re-calibration and new designs; and the derivation of rules of general applicability are discussed.—L. J. L.

Ceramic Tools Pay on Short Runs, Too. G. H. DeGroat. (*Metalworking Prod.*, 1957, **101**, Aug. 16, 1386–1387). Practice at North American Aviation Inc. is outlined.

Cutting Analysis Cuts Costs. W. W. Gilbert. (*Canadian Metalworking*, 1957, **20**, Aug., 32, 34, 36). Machinability research at G.E.C. is reviewed and cutting speed for lowest cost is analysed.

The Machinability Concept. K. G. Lewis. (*Metal Treatment Drop Forging*, 1957, **24**, Aug., 331–334; Sept., 351–357). Chip formation, hardness and its relation to machinability, tensile properties and equations developed from it, microstructure, tool material, abrasive action, cutting temperature and factors in tool life are reviewed. (94 references).

Fabrication of Clad Steels. H. F. Peters. (*Product Eng.*, 1956, **27**, Mid-Oct., D18–D19). A brief account is given of the advantages and properties of clad steels, and the machining, welding, flame-cutting and finishing of such steels is described.—E. A. C.

Abrasives in Metallurgy. (*Aciers Fins Spec. Franç.*, 1957, July, 92–105; In English 97–99). Emery, alumina, SiC, rouge and Cr_2O_3 are reviewed, with notes on the abrasion process, mainly historical.

Cost-Cutting with Grinding Wheels. 1. Snagging Wheel Speed Control. 2. Work Pressure and Wheel Selection. 3. Increasing Cut-Off Wheel Efficiency. 4. Cut-Off Wheel Selection. J. A. Mueller. (*Mod. Castings*, 1957, **31**, Feb., 62–64; Mar., 34–36; Apr., 58–59; June, 71–72). Surface speed control, structure, hardness and pressure in foundry snagging operations are discussed. Wheels should operate at the recommended speed, at constant surface speed, as rapidly as available power allows and using softer wheels the harder the material. Changes in grit, grade or thickness of wheels are considered and related to uses.

Principles and Applications of Spark Machining. I. D. W. Rudorff. (*Wire Ind.*, 1957, **24**, Mar., 251–253, 268). The history and theory of the process are briefly outlined, and elementary circuits, bathing fluids, their properties and requirements, and tests with hydrocarbon oils are discussed.

Machining by Electro-erosion. (*Techn. Indust.*, 1957, **35**, Mar., 229–233). [In Spanish]. The principles of this method of machining, its accuracy and applications are given, together with a description of commercial machines supplied for this purpose.—P. S.

Experiments in the Field of Electrolytic Grinding. P. Landberg and J. L. Remmerswaal. (*Metallinst. Publ.* 50, 1957, July, pp. 9). The grinding of WC with Ni-bonded diamond wheels is more rapid though surface quality is not yet as good as with ordinary diamond grinding. The rate of attack is greater with more dilute electrolyte and with larger current per unit area, though surface finish improves with decreasing current. Sparking must be avoided. Further study is required especially on costs.

Designing for Chemical Milling. R. W. Beckim and H. H. Muller. (*Machine Design*, 1957, **29**, 153–156). Stainless steel has not yet been used on a production basis, but it can be chemically milled. The process as applied to non-ferrous materials is reviewed, and the conditions for its possible use are outlined.

Chem-Mill Reduces Fabrication Problems. L. G. Hall. (*S.A.E.J.*, 1957, **65**, Aug., 30–31). A metal etching process for alloy steels, Al, Ti and Mg is outlined.

Accessory Equipment for the Macrophotography of Machined Surfaces. E. Fuchs. (*Kohászati Lapok*, 1955, **10**, *Ontöde*, Aug., 179–181). An accessory device is described which is applicable to light field illumination for the macrophotography of machined surfaces. The equipment can be mounted on any kind of miniature camera that is equipped for specular reflection and interchangeable objectives. It may be used with an accumulator if electric power is not available.—P. K.

CLEANING AND PICKLING

How to Abrasive Finish Cast Iron. C. F. Walton. (*Metalworking Prod.*, 1957, **101**, Aug. 16, 1421–1423). An account of grinding, honing and lapping is given. Machines are reviewed and grit sizes indicated.

Morphology of the Surface of V2A Steel, Polished in Gases. E. Brüche and K.-J. Schulze. (*Metalloberfläche*, 1957, **11**, June, 181–189). The prepared samples used by Schmid, Maurer and Steinhausen (*ibid*, 1956, **10**, 289), for investigating the chemical polishing of V2A steel with mixtures of gaseous HCl, H_2O and NO_2, were investigated under the electron microscope by the authors. A number of these photographs are reproduced, and the conclusions drawn from their study are discussed.—L. D. H.

Continuous Shot Blast Treats Coil Stock. T. M. Rohan. (*Iron Age*, 1957, **180**, Aug. 8, 92–93). The working of a continuous shot blast line for the surface preparation of hot rolled sheet steel is described; it can handle plate or coil stock 12 to 66 ins. wide.—D. L. C. P.

Treatment of Surface before Painting or Greasing of Metals Such as Steel, Aluminium and Zinc. C. Hess. (*Corrosion et Anti-Corrosion*, 1957, **5**, Jan., 19–24). A review of phosphating processes and other chemical treatments.

New Chemical and Electrolytic Pre-treatments Preliminary to Electro-plating. H. W. Dettner. (*Metall*, 1957, **11**, June, 498–500). Methods for the removal of scale, rust and like coatings from steel and for degreasing are summarized. Among the former special mention is made of electrolytic pickling and alkaline derusting processes; among the latter, vapour phase degreasing, ultrasonic and electrolytic processes.

Anti-Corrosion Lining of Pickling Baths with a Polyiso-Butylene Underlay. V. L. Vinarskii. (*Stal'*, 1957, (3), 272–273). [In Russian]. The author describes the main types of pickling-bath construction used in the Dnieper and Southern regions and suggests that polyisobutylene could be substituted for rubber in the underlay with technical and economic advantages.—S. K.

PROTECTIVE COATINGS

New Materials that the Design Engineer Should Know About: Coatings and Finishes. H. J. Reindl. (*Mech. Eng.*, 1957, **79**, Aug., 730–732). A brief review of metallic and organic coatings is given.

The Physical Properties of Electrodeposited Metals. T. E. Such. (*Metallurgia*, 1957, **56**, Aug.; 61–66; Sept., 121–124). A review of the wide range of tensile strength, ductility, hardness and internal stress obtainable in platings is given. The effect on these coatings and on the plated articles of change in these properties is described and methods of measurement are considered. Cr, Cu, Ni and Zn are surveyed.

The Electro-plating of Screws and other Small Parts, Pt. 4. W. Peters. (*Draht*, 1957, **8**, Apr., 127–131). In this instalment, problems of the control of quality in the process and of costing are dealt with. Regarding the former, methods for the continuous measurement of the coating thickness and of corrosion resistance are mentioned and methods for the electrolytic and chemical removal of metallic salts from spent liquor are listed. Several examples of cost calculation are quoted in which details of equipment costs as well as of running costs are quoted.—J. G. W.

The Protection of Threaded Parts by Electroplating. E. A. Ollard. (*Corrosion Prevention and Control*, 1957, **4**, Aug., 41–44). A review of methods and control.

Pinholes or Porosity in Electrodeposits. J. M. Odekerken. (*Corrosion et Anti-Corrosion*, 1956, **4**, Dec., 403–407). Effects where the coating is more or less active than the basis metal and the causes of porosities and their recognition and elimination are discussed. Porosities may occur through defects in the basis metal, through defects in the preliminary chemical treatment or through suspended matter or dissolved impurities in the plating bath.

Chromium Crack Free and Bright. (*Steel*, 1957, **141**. Aug. 19, 173–180). The application and properties of "Unichrome Bright Crack-Free Chromium" are described. Crack-free chromium plate can now be obtained in a bright finish and has superior corrosion resistance to conventional coatings.

Effect of Chromium Plating on Fatigue Strength of Steel. C. Williams and R. A. F. Hammond. (*Product Eng.*, 1956, **27**, Mid-Oct., C2–C5). A description is given of experiments carried out to determine the relationship between the internal stress in the electrodeposit and the fatigue limit of a chromium plated steel, also how subsequent heat treatment affected this dependence. It is shown that a linear relationship exists and that for certain steels heat treatment will largely reduce the loss in fatigue strength as a result of plating.

Effect of Addition Agents on the Plating of Nickel. A. Goswami. (*J. Sci. Indust. Res.*, 1957, **16B**, July, 315–317). An electron diffraction study. High cathode polarization is produced promoting outward growth deposits.

The Effect of Silicon in a Low-Alloy Steel on the Adhesion of Heavy Nickel Plating. J. J. Dale and H. K. Lutwak. (*Bull. Inst. Met. Finishing*, 1957, **7**, Summer, 133–138). Adhesion failures suggested that anodic etching in sulphuric acid oxidizes the Si forming a film preventing adhesion of Ni. This was confirmed by NaOH treatment which would remove the film.

Nickel in Hard-Facing Alloys. P. Meyer. (*Revue du Nickel*, 1956, **3**, July/Sept., 53–58). The composition and properties of hard-facing alloys containing nickel are discussed. Particular reference is made to their application as abrasion, erosion and corrosion resistant layers on softer ferrous and non-ferrous alloys. Varying properties are obtained by choosing appropriate compositions. These alloys can be used for repairing machine parts and tools.—R. P.

Hot Dip Galvanising. (*Corrosion Protection and Control*, 1957, **4**, Aug., 44–46). A general review of the protective qualities of zinc, methods and uses.

Continuous Galvanizing of Steel Band at Stelco. C. H. Steele. (*Trans. Canad. Inst. Min. Met.*, 1956, **59**, 412–413). A brief account of coating with Zn with added Al of a prefluxed steel band is a low-frequency induction heated bath is given.

Metallographic Study of Hot-dipped Zinc Coatings. A. T. Baldwin and W. H. McMullen. (*Wire and Wire Prod.*, 1957, **32**, June, 662–663). Examples of the structure of hot-dipped zinc coatings on sheet and wire are shown to illustrate the effect of process speed and Al inhibitor to suppress the formation of iron–zinc alloy.—J. G. W.

The Sherardizing Process: Influence of Shape on the Depth of Sherardized Layers and on their Corrosion Resistance. L. Matteoli and F. Barigozzi. (*Met. Ital.*, 1957, **49**, May, 355–362). [In Italian]. Theoretical and practical information is given on the Sherardizing process in which steel is coated with zinc by diffusion in the solid state. The authors describe results obtained in the sherardizing of hollow and tubular parts. Conditions required to obtain adequately thick deposits showing good corrosion resistance are specified. Results of accelerated corrosion tests are also discussed.

The Use of Flux in Galvanizing. A. Herz. (*Mét. Constr. Mécan*, 1957, **89**, May, 463–464). The essential characteristics of a galvanizing flux and its action in zinc baths are discussed. The use of NH_4Cl, $ZnCl_2$ and ZnF_2 is explained together with the influence of water.—B. G. B.

Electroplating of Zinc on Steel Plates. F. H. Smith. (*Corrosion et Anti-Corrosion*, 1957, **5**, Jan., 10–18). A review of installations in several countries, with notes on uses, welding and painting and economic factors.

The Industrial Electrodeposition of Zinc on Steel Plate. G. Pieltain, J. Deheneffe and P. Lemal. (*Corrosion et Anti-Corrosion*, 1956, **4**, July-Aug., 233–240). A review of surface preparation. Factors in the resistance to corrosion, brine tests, phosphatation and chromate treatment, the structure of the deposit, fabrication and welding of the plated sheet, painting and uses are briefly described.

Low Cost Automatic Plant for Electroplating. H. Silman. (*Corrosion Protection and Control.*, 1957, **4**, Aug., 47–50). A review of available machines with description of the Efco-Udylite "Junior" and the "Little Steve" installations for zinc and other plating is given.

Antifouling Properties of Zinc Coatings. E. W. Skerrey. (*Chem. Ind.*, 1957, Sept. 21, 1275). A letter. Sprayed coatings have been found equal to good antifouling paints.

Means for Reducing Retinning of White Tinplate. N. S. Smirnov, A. V. Kineeva and T. B. Bokareva. (*Stal'*, 1957, (8), 731).

Hot-dip Aluminized Steel. K. Zimmermann. (*Z. VdI.*, 1957, **99**, Jan. 1, 9–10). Hot-dip aluminizing of steel strip and wire and of finished parts are briefly described, and the structure, mechanical properties and resistance to corrosion and to heat are discussed. Uses of aluminized steel are enumerated.

Aluminium Dip Coated on Steel Parts. R. F. Joy. (*Steel*, 1957, **140**, Feb. 4, 105–106). A process developed by Bethlehem Steel Co. gives an Al coating which is immune from atmospheric corrosion. The parts are cleaned, then dipped in a preheating-and-fluxing furnace and an aluminium coating furnace before being centrifuged and quenched.—D. L. C. P.

Aluminium Coating, Oil Tempering Discussed by Wire-makers. (*Steel*, 1956, **139**, Dec. 3, 128–134). A report from the Annual meeting of the Wire Association, Pittsburgh, is presented. The following were discussed. Aluminium coating of steel wire: the effect of operating conditions and alloying elements. Production of high quality oil tempered wire: process control and use of zirconium additions.—D. L. C. P.

Aluminizing Iron and Ferrous Metals. L. Grand. (*Rev. Aluminium*, 1957, **34**, Jan., 63–72). The process, which, as yet, is only applicable to relatively small pieces, is described. Oxide films must be eliminated at the interface and the brittle intermetallic zone kept to a minimum, a flux or a reducing atmosphere is used after sand blasting or pickling. Small amounts of Si in the bath are favourable. The resistance to corrosion and the uses of the product are outlined.

Note on Hot-Sprayed Metal Coatings from Oxy-acetylene or Oxy-propane Pistols. J. Cauchetier. (*Galvano*, 1956, **25**, Dec., 43–47). Adhesion and structures are discussed and the condition of various sprayed metals after exposure to corroding media is tabulated.

Flame-Spraying Pistol Working Without Air Blast. W. Kneisel. (*Z. VdI.*, 1957, **99**, Apr. 21, 532). A new type of spraying pistol is described. It has been developed by the Metallizing Engineering Co. of Westbury, N.Y., U.S.A. for the thermo-spraying of metal and ceramic powders.—J. G. W.

Sprayed Metal as a Base for Paints. H. S. Ingham. (*Corrosion*, 1957, **13**, Apr., 252–256). Where long paint life is required blast-cleaning is advisable. Then thin (2–4 mil) sprayed coatings of Zn or Al as a base for the paint are inexpensive. They are easy to paint, and improve appearance and performance. Surface preparation is discussed together with types of paint failure with particular reference to underground power plants. The selection of paints and their application are briefly discussed.—J. F. S.

Present State and Developmental Trends of Metal Spraying. H. von Hofe. (*Z. VdI.* 1957, **99**, April 1, 425–426). The proceedings of the 1956 international conference on metal spraying at Halle a.d. Saale, are summarized under headings of research and development, equipment, and applications.

On Passivation of Steel in Nitration Acid. E. I. Litvinova. (*Zhur. Priklad. Khim.*, 1954, **29**, (10), 1521–1529). [In Russian]. It was shown that the passivation of steel in HNO_3–H_2SO_4 mixtures is caused not by the formation of a film but by the precipitation on the surface of the steel of a dense layer of ferric sulphate. The best results are obtained on treatment of steel in a mixture at 100° C, when a 3μ thick sulphate coating is formed which protects steel at high and low temperatures. Non-metallic inclusions and other impurities do not interfere with the passivation process. Covering the surface with zinc slows down passivation.—V. G.

Phosphating. Further Development of a Sludge-Free Process. F. Rossteutscher. (*Mitteilungen für die Mitglieder der Forschungsgesellschaft Blechverarbeitung*, 1953, (12), 1–3). A combined phosphate–oxalate process is described.

A Method for Determining the Electrical Resistance of Phosphate Coatings on Steel. J. W. Scott and L. L. Shreir. (*Chem. Indust.*, 1957, June 22, 807–808). The resistance was measured as a criterion of anticorrosive effect. A method for making a mercury contact with the surface is described.

Asphalt Type Protective Coatings for Underground Pipe Lines.—Mastic Systems. NACE Technical Unit Committee T–2H. (*Corrosion*, 1957, **13**, May, 347–350). Systems are described and specifications are advanced for materials, methods of application and minimum satisfactory service. Bond strength measurements are appended.

Coatings for Crude Oil Tank Bottoms. R. M. Carter. (*Corrosion*, 1957, **13**, Apr., 270–276)' A laboratory method which has been successfully used for screening coatings for inside crude oil tank bottoms is described. A coal tar–epoxy resin compound and two hot-applied coal tars are recommended. The variations in corrosive media are discussed briefly and the differing application problems for 'thick' and 'thin' coatings are compared. Cathodic protection inside the tanks is mentioned.—J. F. S.

How Plastics Curb Corrosion in Metal Processing. J. H. Lux. (*Iron Age*, 1957, **179**, Jan. 17. 80–82). Applications of plastics to metal-treating baths, fume scrubbers, piping, and exhaust stacks under corrosive conditions is described.

New Directions for Porcelain Enamel. (*Steel*, 1956, **139**, Dec. 3, 142–143). Recent trends in the processes of porcelain enamelling and in applications of the coating are discussed. One report concerns porcelain enamelled aluminium foil: it is flexible and has a future for decoration, anti-corrosive applications and in electronics.—D. L. C. P.

The Influence of Iron Oxides on Thermal Expansion of Enamels. A. A. Apen, R. I. Bresker and L. A. Kuznetsova. (*Zhur. Priklad. Khim.*, 1956, **29**, (11), 1753–1755). [In Russian].—V. G.

Chemical and Electrochemical Properties of $FeSn_2$. R. A. Covert and H. H. Uhlig. (*J. Electrochem. Soc.*, 1957, **104**, Sept., 537–541). Microhardness measurements of Fe, Sn and $FeSn_2$ layers formed on exposure of iron to tin at 465° show $FeSn_2$ to be much the hardest. It is also most resistant to acidified NaCl or dilute citric acid. Hydrogen overvoltages are also measured and properties are related to corrosion behaviour in tin plate.

Corrosion Prevention by Cadmium Plating. P. F. Norrish. (*Corrosion Protection and Control*, 1957, **4**, Aug., 51–53). A description, a comparison with zinc, a brief description of the process and an outline of uses are given.

Protective Plating Equipment. K. D. Roberts. (*Corrosion Prevention and Control*, 1957, **4**, Aug., 54–56). Hand operated and barrel plants for Cd and Cu plating are described, with notes on uses.

Hot Dip Aluminizing Widens Cast Iron Uses. (*Iron Age*, 1957, **180**, Aug. 8, 87). The results of a new hot-dip Al coating process for grey and malleable iron are described. The coatings have a bright finish, and their resistance to corrosion and high temperature oxidation is equal to that of highly alloyed types of base-metal.—D. L. C. P.

Metallising. (*Tecn. Indust.*, 1956, **34**, Dec., 1787–1792). [In Spanish]. A brief review of the techniques of metal spraying are given together with examples of its application to building up worn parts and for protection against corrosion.

Further Developments of the Technique of Metal Spraying. H. Reininger. (*Metalloberfläche*, 1956, **10**, June, 181–185; Nov., 337–343). A general review is given of the literature dealing with recent developments in the field of metal-spraying and testing techniques. (109 ref.).—L. D. H.

The Mechanism of the Protection of Steel by Sprayed Aluminium Coatings. J. E. O. Mayne and B. Van Rooyen. (*Chem. Ind.*, 1957, June 8, 718–721). A study of sprayed mild steel is described in which electrical measurements were made in tap-water, sea water and in salt solutions. Evidence is presented that all the Al is in metallic contact with the steel, that the sprayed coating was more reactive than massive Al and that cathodic protection occurs. Protection appeared to be due to blockage of pores in the coating.

Black Oxide Coatings on Steel: Quality Tests. J. Doss. (*Electroplating Metal Finishing*, 1957, **10**, Sept., 289–290). An oxalic acid spot test is described. Steel panels were treated in an alkaline oxidizing bath, and ground and sand-blasted surfaces were tested. On good quality coatings a black or dark brown colour is produced in 3–8 min, but poor coatings become grey in < 3 min. Imbibition, humidity cabinet and citric acid and ammonium citrate tests were unreliable. The new test is recommended instead of the $\frac{1}{2}$ hr. salt fog test.

Kinetic Studies on Formation of Black-Oxide Coatings on Mild Steel in Alkaline Nitrite Solutions. R. M. Hurd and N. Hackerman. (*J. Electrochem. Soc.*, 1957, **104**, Aug., 482–485). Formation of magnetite coatings was studied in hot concentrated NaOH–$NaNO_2$ solutions at 130–150° C. A mechanism for the reaction is proposed and rate constants calculated. With thick films the rate appears to be diffusion-controlled.

The Formation of Oxide Films on Chromium and 18 Cr–8Ni Steels. H. J. Yearian, W. D. Derbyshire and J. F. Radavich. (*Corrosion*, 1957, **13**, Sept., 597–607). Electron microscopical studies of film formation at 300–700° C, and also by electron diffraction and X-ray methods are reported. A thin uniform film appears in a few min and grows very slowly. As oxidation proceeds protectiveness fails at random points and nodules grow. This continues until the film is covered at a rate depending upon composition and temperature. The principal component is a solid solution of ferric and chromic oxides oriented preferentially to the (111) plane. Some spinel may be present.

The Phosphation of Ferrous Metals. J. Demesse. (*Métaux-Corrosion-Indust.*, 1957, **32**, Apr., 172–175). Methods of phosphating the surface of ferrous metals in order to increase the resistance to corrosion are described. The use of zinc and manganese phosphates is reviewed. Present production techniques employed in U.S. and elsewhere are discussed. A method of determining the thickness of the phosphate layer is reported.—B. G. B.

Phosphatation in the Solvent Phase. J. Baudin. (*Corrosion et Anti-Corrosion*, 1956, **4**, July-Aug., 252–256). A process using mixed phosphates in an organic solvent is referred to and exposure tests are quoted for Fe, Fe–Zn and Fe–Mn phosphates and Fe–Zn in a solvent. An analogy with glyptal and polyester formation is sketched. Trials on the hull of a ship after 17 month's service are described.

Conversion Coatings for Metals. R. J. Fabian. (*Materials in Design Engineering*, 1957, **46**, Aug., 121–130). A review of chemical and electrochemical coatings for iron and non-

ferrous metals including phosphate, chromate, anodizing and oxide and similar coatings is given, with an account of properties and uses.

How to Protect Metals with Elastomeric Linings. L. A. Woerner. (*Materials in Design Engineering*, 1957, **46**, Aug., 94–98). An account of natural and synthetic rubber and other plastic linings with a table of resistance to a large number of chemicals is given.

Vitreous Enamelling on Steel and Cast Iron. J. W. G. Pedder. (*Corrosion Prevention and Control*, 1957, **4**, Aug., 37–40). A general review of compositions, surface preparation, application and uses is given.

What Glass Can Offer Metal. C. E. Bulloch and F. Nelson. (*Steel*, 1957, **141**, Aug. 19, 154–156). The method of glass-coating metal parts is indicated and applications for the technique are described. Glass can be firmly bonded to low carbon steel for industrial applications involving resistance to weather and corrosion, nonporosity, high dielectric strength, and resistance to high temperatures.—D. L. C. P.

Wettability in Enamel–Metal Systems. R. M. King and R. L. Cook. (*Amer. Ceram. Soc. Bull.*, 1957, **36**, Aug., 293–296). The investigation reported was to study the factors affecting the wetting of iron by fused enamel. The results indicated that fused ground-coat enamel did not wet unoxidized iron, but did wet oxidized iron. When the furnace atmosphere contained 0·6% or 1·6% moisture, the wetting of oxidized iron by fused ground-coat enamel was improved. One-coat type titanium white enamel did not wet the iron as well as the ground-coat enamel.—D. L. C. P.

Approved Method of Applying Cermet Coatings. (*Engineer*, 1957, **204**, Sept. 20, 436, 437). The N.B.S. process using a Cr–B–Ni mixture and a ceramic frit is described. Micrographs of iron and steel coated in the way and fired in air at 1500–1950° F are shown.

Defects in Cast Iron for Enamelling Purposes. P. Göbbels. (*Foundry Trade J.*, 1957, **103**, Sept. 26, 363–366). Cracking, spalling, blistering and other defects in enamel coats are traced to faults in the cast iron, and improvements in casting technique are advocated to reduce rejects in emamelled products.

Effect of Surface Conditions of Steel on Protection Given by High-Zinc Paints. G. Binetti and G. Ghisolfi. (*Met. Ital.*, 1957, **49**, May, 327–332). [In Italian]. The authors establish the electrochemical nature of steel corrosion and the part played by zinc as an anodic inhibitor in protecting steel. The application of zinc in the form of high zinc paints is discussed. The electrochemical process of protection here is similar to that given by galvanizing. The importance of surface preparation to get the best results from zinc paints is stressed and various methods of surface preparation, especially for the removal of mill scale, are discussed.—M. D. J. B.

Painting Weldments. R. Clement. (*Prat. Soud.*, 1957, **11**, Feb., 29–33). [In French]. The authors discusses the deterioration of paints over weldments. The principal causes of corrosion and the action of rust on oil paints are described. Means of overcoming paint deterioration are reviewed.—M. D. J. B.

Red Lead in the Protection of Iron and Steel. (6). H. Masseille. (*Corrosion Prevention and Control*, 1957, 4, Sept., 41–43). A final article in a series deals with the legal, toxiological and safety aspects of red lead, and with specifications for powder and paste.

POWDER METALLURGY

Design for Powder Metal Parts. R. Talmage and J. Kolb. (*Product Eng.*, 1957, **28**, Aug., 183–190). A review, mainly of iron powder metallurgy, with illustrations of typical parts, is presented.

Strengthen Powdered Iron Parts With Steam. F. L. Spangler and M. E. Lackey. (*Iron Age*, 1957, **180**, Aug. 1, 98–99). The value of treating powdered iron parts with superheated steam is explained. Improvements concern:— strength, hardness, corrosion-resistance, oil retention, colour-finish and elimination of porosity.—D. L. C. P.

Sintered Steel Parts. R. Talmage. (*Machine Design*, 1957, **29**, June 27, 110–112). Physical properties and their dependence on sintering conditions are discussed. Effects of time, temperature and atmosphere are shown, and the effects of adding Cu and C. Density variation is reviewed, and uses in design and cost factors are noted.

Model Sintering Tests in Liquid Media. F. Eisenkolb and T. Kalning. (*Planseeberichte*, 1957, **5**, Apr., 2–19). After discussing the various theories put forward for the explanation of sintering processes, the authors describe the effect of molten salt and metal and of a surface activated by decomposition of a solid solution on sintering processes. It is not possible to determine the coefficient of diffusion of metals by using the solid model. Suitable chemical reaction will result in activation. Sintering is influenced by the decomposition temperature and depth of solid solution. Lattice irregularities of the activated surface will increase the rate of transfer at lower temperatures only if the metallic melt alloys with the solid component. (27 references).—E. P.

PROPERTIES AND TESTS

Continuous Inspection Methods in Industrial Manufacture. M. Dühmke. (*Metall*, 1957, **11**, July, 579–582). Recently developed instruments and devices for continuous inspection are briefly described under the following headings:— sampling inspection, automatic measurement, measurements with continuous indication and with automatic stoppage of process, machine tools controlled by measuring instrument.

The Present State of Grey Cast Iron Examination. T. Lukacsfalvi. (*Kohászati Lapok*, 1953, **8**, *Ontöde*, Aug., 179–184; Sept., 196–201). The author reviews the various mechanical tests for grey cast iron i.e. tensile, hardness, bend, pressure, shear, impact, fatigue, damping, creep and wear tests. Afterwards he comments on testing for corrosion and heat-resistance, for volume stability, for electric, thermal and magnetic properties. Finally reference is made to non-destructive methods e.g. ultrasonic testing and radiological examination.—P. K.

Results of Mechanical Tests Carried out on Spheroidal Graphite Cast Irons. E. Di Giacomo. (*Calore*, 1957, **28**, May, 187–195). [In Italian]. After defining spheroidal graphite cast irons, the author describes the methodology used in the extensive series of mechanical tests carried out. The results of the tests are given and 18 tables of technical data are reproduced.—M. D. J. B.

Function and Nature of Surfaces Encountered in Technology. W. Schmidt. (*Metall*, 1957, **11**, June, 473–480). This is a broad survey of the problem of defining the condition and specifying the practical requirements of metallic surfaces for application in bearings, gears, glands, and instruments, with a discussion of microgeometry, texture and wear.—J. G. W.

Thoughts on the Quality of Steels. R. Calvo Rodes. (*Tec. Met.*, 1956, **12**, Sept.-Oct., 157–163). [In Spanish]. The author discusses the difficulty in defining quality and suggests that the actual cohesive strength of the structure provides a measure of the true quality. In connection with this, plasticity, theoretical strength, brittle fracture, and temper brittleness are discussed.—P. S.

The Dynamic Testing of Materials. J. J. Fernandez Fernandez. (*Met. Elect.*, 1956, **20**, Feb., 52–57; May, 54–60; June, 132–137; Nov., 59–64; Dec., 68–74; 1957, **21**, Jan., 94–97; Feb., 52–55). [In Spanish]. This series of papers provides a review of the theory and practice of mechanical testing under the following headings: (i) impact strength, (ii) tensile tests, (iii) compression tests, (iv) torsion tests, (v) fatigue tests, and, in addition, describes typical machines, specimen data and results.—P. S.

Interpretation of Fracture Patterns. C. Lipson. (*Product Eng.*, 1956, **27**, Mid-Oct., A2–A6). The points of origin of a failure are briefly outlined, and for different methods of loading the appearance of a fracture is discussed.—E. A. C.

On the Stability of the Steel Lining in a Vertical Penstock Shaft. K. I. Karlsson. (*Acta Polytechn.*, 1957, **3**, (211), pp. 22).

The Load-Bearing Capacity of Steel Sections and Their Economic Use for Pit Supports. W. Schaefer. (*Glückauf*, 1957, **93**, 20 July, 877–896). It is shown from the evaluation of a large number of bend tests and from theoretical considerations that the bend factor is of great importance in calculating the load-bearing capacity of steel sections for pit supports. From economic considerations it is considered that steels with an average yield point of 60 Kg/mm² could be profitably used. Economic factors are studied in detail.—L. D. H.

Comments on Impact Tests. W. Späth. (*Metall*, 1957, **11**, July, 598–604). A new impact tester is described in which

both the impact work done and the maximum load are recorded. Some data obtained with it are then quoted, for sintered Al, glass fibre reinforced plastics, and carbides. From these it is concluded that the absorbed impact energy is not a universally valid measure of 'toughness.' Some of the differences between the Charpy and Izod tests are also discussed, so is the effect of the dimensions of the specimen.

Correlation between Specific Impact Values Measured on Charpy and Mesnager Specimens. N. Hajtó. (*Kohászati Lapok*, 1955, **10**, March, 136–137). The author calculated from about 1000 experimental results the following correlation between impact values x of Charpy (55 × 10 × 5 mm) and y of Mesnager (55 × 10 × 8 mm) specimens: $y = 0{\cdot}04$, $x^2 + x$, or up to 8 mkg per cm², $y = 1{\cdot}25x$, and above 8 mkg per cm² $y = 1{\cdot}75x - 4$.—P. K.

The Influence of Heat-Treatment upon the Impact Properties of Spheroidal Graphite Cast Iron. J. H. Gittus. (*Inst. Brit. Found. J.*, 1957, **50**, Sept., 466–474). Fully annealed specimens have excellent impact properties and heat treatments aimed at further improvement by tempering the ferrite or reducing grain size was sought. Specimens cooled rapidly from ferritizing temperature can be toughened by tempering 1 h at 300–350°, longer times cause embrittlement. Effects of varying grain size are described. This can be done by low-temperature ferritization (~ 600° C), by ferritization of upper bainite, and by low-temp. austenitization. The finest ferrite is obtained by combining all three.

The Influence of Microstructure on the Plastic Deformability of Carbon Steels. O. Szabó. (*Kohászati Lapok*, 1938, 5, Feb., 47–48; March, 56–69). For the appraisement of the behaviour of metals during plastic deformation the real stress-reduction of area curves are the most convenient. A photographic method is given for determination of the reduction of area. The behaviour of a carbon steel during plastic deformation depends on the quantity, shape and distribution of cementite. The influence of spherical cementite is insignificant. An increasing quantity of lamellar pearlite augments the tensile strength, but decreases the plastic deformability.—P. K.

Comparison between Torsional and Tensile Stress Relaxation Tests. L. E. Benson, G. E. Tummers and S. J. Watson. (*Brit. Welding J.*, 1957, **4**, June, 281–282). A 0·5% Mo steel was tested at 600° C. Agreement between the methods was found.

Investigation of Internal Friction in γ- and α-phases of High Chromium Steel. Yu. V. Piguzov. (*Doklady Akad. Nauk S.S.S.R.*, 1957, **112**, (4), 636–639). [In Russian]. The internal friction of steel tempered at different temperatures was studied by means of a torsion balance. The samples studied showed peaks at various temperatures on the internal friction/temperature curves. These curves are interpreted on the basis of phase composition and X-ray data of the steels concerned.—S. I. T.

Some New Applications of Microfractography. J. Plateau, G. Henry and C. Crussard. (*Rev. Mét.*, 1957, **54**, Mar., 200–216). A simple method is described for obtaining a replica of the microstructure of a steel sample. The application of the method to the study of the propagation of cleavage rupture is discussed with the assistance of numerous photomicrographs. A study is also reported of the microfractography of intergranular processes. Examination of the modifications of structure occurring as a result of creep in grain boundaries and of intergranular cracking is described.—B. G. B.

Spatial Distribution of Fragments of Explosively Loaded Thin-Walled Steel Cylinders. S. Singh. (*Proc. Phys. Soc.*, 1956, **69B**, Nov. 1, 1089–1094). Most fragments make an angle of 7·5° to the normal to the inner surface of the cylinder and away from the exploder.

The Influence of Plastic Deformation on the Elasticity Moduli of Low Carbon Steel. V. I. Korotkov. (*Fizika Metallov i Metallovedenie*, 1956, **2**, (1), 160–167). [In Russian]. A quantitative determination of changes of Young modulus E and slip modulus G depending on the degree of cold plastic deformation was carried out. A dynamic method in which both moduli can be determined on one cylindrical specimen was used.—V. G.

Deformations of Crystal Lattices of Coarse and Fine-Grain Steel during Cold Plastic Deformation. V. M. Finkel'. (*Fizika Metallov i Metallovedenie*, 1956, **2**, (1), 189–191). [In Russian]. Changes in the intensity of X-ray interference lines of coarse and fine grain steel during plastic deformation were studied. The results obtained for coarse grained steel plotted in the form of the dependence of intensity ratio of the individual lines before and after deformation on the degree of deformation gave horizontal straight lines.—V. G.

Residual Stresses in Cold Drawn Steel Bars and Attendant Fabrication Problems. (*Rév. Gen. Méc.*, 1957, **41**, Feb., 77–78). A short review of the extent of residual stresses in cold-drawn steel bars is presented.—B. G. B.

A New Detection of Fatigue Damage in Metals. A. J. Kennedy. (*Nature*, 1957, **179**, June 22, 1291–1292). Cycles of forward and reverse torsional creep are used with a total cycle period of 40 min. Simple creep and fatigue creep are distinguished.

A Statistical Appraisal of the Prot Method for Determination of Fatigue Endurance Limit. W. A. Hijab. (*J. Appl. Mech.*, 1957, **24**, June, 214–227). The Prot method is found to be less efficient than the probit and staircase methods, and this, with objections to its assumptions, renders its usefulness questionable. A general derivation, of which the Prot method is a particular case, is also presented.

The Influence of Wire Plasticity on the Fatigue Limit of Steel Wire Rope. Z. Glowacki. (*Hutnik*, 1956, **23**, (9), 336–339). [In Polish]. The effects of heat treatment at low temperatures (350° C–500° C) on drawn steel wire were investigated. The samples of the same wire before and after thermal treatment were tested for bending, torsion, and stretching. Also fatigue, metallographic and X-ray tests were carried out.—K. G.

Thermal Stress Fatigue. L. F. Coffin jun. (*Product Eng.*, 1957, **28**, June, 175–179). A review on the origin of thermal stresses, their importance, the measurement of thermal shock resistance, the distinction from mechanical fatigue and design criteria involved is presented. Data for stainless steels, among numerous other materials, are tabulated and steel plate quenching is given as one example.

Czechoslovak and Foreign Standards Relating to Creep Testing. P. Jehlička and R. Schönhöffer. (*Hutnické Listy*, 1957, **12**, (2), 144–149). [In Czech]. Standards relating to creep testing, both Czechoslovak and those of other major industrial countries are discussed and compared. The various specifications are given in detail, and a dictionary of the terminology is provided; the languages covered being Czech, Russian, German, English, and French. Separate columns are given for English and American terminologies.—P. F.

A Note On the Problem of Creep. J. Glen. (*J. Metallurgical Club, Royal College of Science and Technology*, 1956–57, (9), 15–18). Equations previously advanced are reviewed in the light of dislocation theory and hardening processes are considered. A connexion between strain hardening and precipitation hardening may exist.

On the Mechanism of High-Temperature Creep in Metals with Special Reference to Polycrystalline Lead. P. Feltham. (*Proc. Phys. Soc.*, 1956, **69B**, Dec. 1, 1173–1188). Equations are advanced based on Mott's mechanism of fine slip and activation energy for screw dislocations impeded by jigs. An experimental method is described and comparisons with published values for various metals are also made.

The Effect of Prestrains at Room Temperature on the Creep of Low-Carbon Steels. R. Šejnoha. (*Hutnické Listy*, 1957, **12** (2), 102–109). [In Czech]. Results are given of short-time creep tests on a 0·09% C steel containing also 0·21% Cu, 0·08% Ni and 0·06% Cr. The steel had been deoxidized with Al. Prestraining was found to be advantageous at comparatively high stresses. Testing temperatures ranged from 400 to 550° C. Metallographic and theoretical aspects of the results are discussed.—P. F.

Temperature Control in Long-Time Creep Tests. B. Šesták. (*Hutnické Listy*, 1957, **12**, (3), 202–205). [In Czech]. The development and testing of a comparatively sensitive yet cheap temperature controller of the on-off type are described. The difference between the dilatation of the tubular steel furnace and an invar rod is used as the controlling variable. At 300° C temperature fluctuations did not exceed about ± 1° C in tests lasting 200 hours.—P. F.

Method of Determining the Hardness of Brittle Materials, Especially Hard Metals. S. Palmqvist. (*Jernkontorets Ann.*, 1957, **141**, (5), 300–307).

Vickers and Rockwell Hardness as a Function of the Parameters of Plasticity of Metal and Testing Conditions. G. P.

Zaitsev. (*Fizika Metallov i Metallovedenie*, 1956, **2**, (2), 339–350). [In Russian]. Functional dependence of hardness as determined by Vickers and Rockwell methods on the plasticity parameter as determined during stretching, and on experimental conditions was established.—V. G.

The Problem of Brittle Fracture. W. D. Biggs. (*Welder*, 1956, **25**, Apr.–June, 22–27; July–Sept., 48–55; Oct.–Dec., 72–79; 1957, **26**, Jan.–Mar., 2–7). A non-technical review is given. Conditions under which fracture occurs are discussed with a list of failures in service of tanks, bridges and ships from 1886 onwards. Effects of strain rate and grain size are considered and the measurement of transition temperature and the impact, tear, Tipper, explosion and Robertson tests, also composition and rolling effects. Processes of slip in crystals and the behaviour of pure iron and steels and slip and fracture patterns are then discussed and finally criteria, design effects, materials and effects of welding are outlined. (87 references).

The Nature of Strain-age Embrittlement. C. J. Osborn. (*J.I.S.I.*, 1958, Feb., **188**, 97–101). [This issue].

A New Look at Temper Brittleness. G. K. Bhat. (*Iron Age*, 1957, **179**, Jan. 24, 73–77). The problem of temper brittleness is considered, its cause and preventions. There is evidence that a grain boundary precipitate may be responsible.

The Effect of Cold Reduction on Reversible and Irreversible Temper Brittleness. M. M. Shteinberg, V. D. Sadovskii and A. V. Demakova. (*Metallovedenie i Obrabotka Metallov*, 1956, **2**, June, 26–35). Steel with 0·02% C, 0·08% Si, 0·07% Mn, 1·45% Cr, 4·06% Ni, 0·017% S and 0·015% P was used. Rolled specimens were heated to 1200° C, quenched, and tempered at 50° intervals from 200–450°. Impact values were measured after notching. N8 and KhIN 3·5 steels were also examined. Cold reduction increased impact strength and the curves show maxima. Brittleness appears to be due to decomposition of a supersaturated solid solution.

The Brittle Fracture of Iron and Steel. N. P. Allen. (*Tek. Ukeblad*, 1957, **104**, May 9, 375–383). [In English]. The nature of brittle fracture is described, and factors influencing the transition from ductile to brittle fracture are discussed, including the effects of chemical composition and physical properties. The article concludes with a description of methods for testing susceptibility to brittle fracture. (12 ref.).

Embrittlement of Phosphated Steel. H. P. Weinberg and T. J. Capello. (*Metal Progress*, 1957, **71**, Apr., 78–81). The embrittlement of a Cr–Ni–Mo steel (F.S. 4340) which has been heat treated to give high strength is described. Phosphate coatings, either zinc or manganese base, cause embrittlement, but this can be prevented by ageing for 24 h at room temperature or by baking 1 h at 220° F.—B. G. B.

Embrittlement of 12% Cr Steel Thermocouple Nozzles on a Thermofor Catalytic Cracking Unit Reactor. H. H. Bennett. (*Corrosion*, 1957, **13**, Feb., 87t–88t). Nozzles cracked after 100,000 h at 850–1000° F and grain-boundary widening, apparently due to precipitation, was observed near the brittle zone. Sigma-phase may be the cause.

Hydrogen Embrittlement of Steel. W. Rostoker. (*Steel*, 1956, **139**, Nov. 12, 138–144). The effects of hydrogen embrittlement are explained and its cause considered.—D. L. C. P.

On the Mechanism of the Influence of Phosphorus and Molybdenum Admixtures on Temper Brittleness of Steel. V. I. Arkharov, S. I. Ivanovskaya, N. M. Kolesnikova, and T. A. Fofanova. (*Fizika Metallov i Metallovedenie*, 1956, **2**, (1), 57–65). [In Russian]. The influence of phosphorus on reversible temper-brittleness was investigated on Cr–Ni and Cr–Ni–Mo structural steels. Experimental results indicated that phosphorus participates in the phenomena of temper-brittleness. An increase in the phosphorus concentration on the surface of brittle fracture indicates that during thermal treatment it concentrates preferentially on the boundary of austenite grains. In steel containing molybdenum the appearance of a phosphorus diffusion front is less pronounced than in Cr–Ni steel. Thus the role of molybdenum is that its presence in the solid solution containing also phosphorus decreases the intercrystalline internal adsorption of the latter in comparison with a solid solution of similar composition but without molybdenum.—V. G.

Relationship Predicts Abrasive Resistance of Steel. M. M. Tenenbaum. (*Mat. Methods*, 1957, **45**, June, 159, 161; *Vestnik Mashinostroeniya*, 1956, (8), 25–30). Tests with 21 types of steel showed that the ratio of Vickers hardness of steel to Vickers hardness of abrasive is a determining factor in the resistance of steels. At ratios below 0·5–0·6 wear does not depend on abrasive hardness and wear resistance is practically linearly related to steel hardness. When the ratio is higher the effect of improved steel hardness is more pronounced. With constant hardness higher C content improves wear resistance; alloying elements have no significant effect. Effects of peening, carburizing, nitriding and chromizing are also discussed.

Wear of Metals by Erosion and Protective Coatings. A. V. Shreider. (*Fizika Metallov i Metallovedenie*, 1956, **2**, (1), 181–188). [In Russian]. Wear of metals by erosion and abrasion caused by high velocity gas streams was investigated. Resistance to wear by erosion cannot be characterized by hardness of metal as determined by impression, scratching or resistance to wear by friction. A method for investigating wear of materials by abrasion and erosion is proposed. Empirical relationships between erosion and the velocity and angle of incidence of impinging particles, hardness of the metal and the state of the surface were established. Relative resistances to erosion of a number of structural alloys were determined. Protection of ferrous and non-ferrous metals can be obtained by hard chromizing.—V. G.

The Effect of Heat-Treatment of Railway Tyres on their Wear-Resistance. S. Hořejš. (*Hutnické Listy*, 1957, **12**, (3), 277–287). [In Czech]. The suppression of the formation of pro-eutectoid ferrite by quenching and tempering is shown to lead to increased wear resistance in 0·43 and 0·56% C railway tyres. Normalized tyres with a ferrite-pearlite structure have the worst wear properties, particularly if the pearlite lamellae are well defined.—P. F.

Dry Friction of Some Aluminium Alloys and Steels. F. Bollenrath and H. Grefkes. (*Aluminium*, 1957, **33**, Apr., 234–240). A review of present knowledge and methods of determination of coefficients of friction, and of cold welding, frictional oxidation and gas uptake. W and WC were also used and frictional behaviour is correlated with readiness for cold welding. Besides static and sliding friction, a third variety, cold welding friction, is distinguished. The work has special reference to the behaviour of pit props. (38 references).

Study of the Wear of Tungsten Carbide Tools with the Help of Radioactive Tracers. H. Creuzot and P. Lévêque. (*Rév. Gen. Méc.*, 1957, **41**, Feb., 57–60). The experimental technique used is described and full details showing how the results are calculated from the practical measurements made are given.—B. G. B.

Calorizing of Gas-Turbine Blades of Austenitic Steel. V. I. Prosvirin, A. I. Fedosov and Yu. S. Myakishev. (*Metallovedenie i Obrabotka Metallov*, 1956, **2**, Apr., 50–56). Erosive wear by fuel ash particles was studied in a special apparatus. Aluminized materials with or without chromizing and homogenizing treatments were tested. Results are shown graphically.

On the Structure of "White Zone." L. S. Palatnik, I. M. Lyubarskii and B. T. Boiko. (*Fizika Metallov i Metallovedenie*, 1956, **2**, (2), 285–293). [In Russian]. Metallographic and X-ray investigation of a defect ("seize") appearing on teeth of gear wheels under heavy frictional conditions was carried out. It was found that this defect is accompanied by the appearance of "white zone" representing an austenite–martensite structure. Some data on the nature and properties of this zone are given.—V. G.

Electronic Fluoroscopy with Image Intensification. A. L. Gobus. (*Non-Destructive Test.*, 1957, **15**, Mar.–Apr., 100–102). Applications to thick steel and other sections are described.

New Measurements of the Gyromagnetic Ratios of Iron and Nickel. A. J. Meyer and S. Brown. (*J. Phys. Radium*, 1957, **18**, March, 161–168). Apparatus is described and values leading to a final mean of $1{\cdot}035 \pm 0{\cdot}002$ for the m/e ratio for Fe.

The Electrolytic Migration of Carbon in Steels. W. Hume-Rothery. (*J.I.S.I.*, 1958, Feb., **188**, 113). [This issue].

The Influence of the Rate of Cooling During Thermomagnetic Treatment on the Magnetic Properties of Cold-rolled Transformer Steel. D. Mishin and M. M. Belenkova. (*Fizika Metallov i Metallovedenie*, 1956, **2**, (2), 371–374). [In Russian]. The dependence of magnetization curve, magnetostriction and coercive force on the rate of cooling during thermomagnetic treatment of the above steel was investigated. Anisotropic effects of the above treatment were observed. The largest effect is obtained when the magnetic field is applied at 60° to the direction of rolling and a lower effect when in the direction of rolling.—V. G.

Changes in Domain Structure Accompanying Reduction in Depth of a Single Crystal of Silicon Iron. L. F. Bates and A. Hart. (*Proc. Phys. Soc.*, 1956, **69B**, Dec. 1, 1200–1204).

'Lozenge' and 'Tadpole' Domain Structures on Silicon–Iron Crystals. L. F. Bates and P. F. Davis. (*Proc. Phys. Soc.*, 1957, **69B**, Nov. 1, 1109–1111).

Electrical Conductivity at Very Low Temperatures of Very Pure Metals and Application to Recrystallization Phenomena. M. Caren. (*Publ. Sci. Techn. l'Air*, 1957, (328), pp. 58). Chemical analysis of the iron used, the apparatus for conductivity measurements, and the heat-treatment leading to maximum conductivity as well as the variation of resistance with temperature at 14–20·4° K are shown.

Flaw Detection by Eddy-Current Methods. G. O. McClurg. (*Non-Destructive Test.*, 1957, **15**, Mar.–Apr., 116–119). Theory is outlined showing the kinds of flaws that can be detected, and their indentification, and the assessment of their severity.

Ultrasonic Control of Forged and Cast Heavy Pieces. American Position as Regards Acceptance Conditions in this Field. J. Pignet and E. de Kerversau. (*Rev. Mét.* 1957, **54**, Mar., 169–174). After a brief outline of the methods and apparatus used, their application to castings and forgings is described. Each piece is considered in the light of utilization conditions and the forging conditions used. The principal types of defect and their interpretation by ultrasonic techniques are explained and decisions taken on the soundness of the piece for subsequent use are reported.—B. G. B.

Testing of Metals by Means of Ultrasonic Surface Waves. J. Tabin and M. Kurek. (*Hutnik*, 1956, **23**, (7–8), 300–304). [In Polish]. The authors discuss the three types of ultrasonic waves and the methods of their production. The use of the surface ultrasonic waves in the testing of metals for defects has been described. The surface waves are considered to be particularly useful in the detection of faults on the surface of the metal.—K. G.

X-Ray Investigation of Phenomena Accompanying the Prolonged Stretching of Steel at Elevated Temperatures. M. Ya. Fuks, N. V. Slonovskii and L. I. Lupilov. (*Fizika Metallov i Metallovedenie*, 1956, **2**, (2), 328–338). [In Russian]. X-Ray investigation of carbon and chromium–molybdenum steels plastically deformed at room and elevated temperatures at various rates in the range of 5–150% of the residual elongation was carried out. From the widening of maximum interference lines, the degree of diminution of congruent zones and the values of microstresses were quantitatively determined.—V. G.

Radioactive Isotopes in Metallurgy. Yu. V. Kornev. (*Metallurgy*, 1956, (1), 15–19). [In Russian]. In metallurgy, radioactive isotopes are used as (1) sources of penetrating radiation for detection of flaws in ingots and castings, and for gauging thickness of hot rolled steel strip, and, (2) as tracers for various types of research, such as the rate of corrosion of linings, distribution of elements between metal and slag or metal and added alloy, and other problems.—S. I. T.

Radioactive Isotopes in Defectoscopy. T. Florkowski. (*Hutnik*, 1956, **23**, (4), 167–172). [In Polish]. The application of radioactive materials (γ-ray emitters) in photographic and ionization methods of detection of faults in metals is discussed. The choice of radioactive isotopes is indicated. A few notes about safety measures are given.—K. G.

Industrial Radiography by Gamma-Ray Projection from Radioactive Isotopes. C. M. Dick. (*Welding J.*, 1957, **36**, May, 457–462). A review of the process with an account of sources and projectors is given. The method is claimed to be relatively low in cost and simple to use. Applications to welds are indicated.

Some Reflections on the Use of Radioisotopes in Industrial Radiography. With Special Emphasis on the Use of Iridium (192) for the Radiographic Inspection of Structural Welding in Shipbuilding. W. H. Sansom. (*Shipbuilder Marine Engine Builder*, 1957, **64**, May, 329–333).

New Metallurgical Laboratory for B.W.R.A. (*Metallurgia*, 1957, **56**, Sept., 137–140). A description of the British Welding Research Association laboratories at Abington Hall.

The Travelling Foundry Laboratory of the Institute for Foundry Engineering. A. Knickenberg. (*Giesserei*, 1957, **44**, Apr. 25, 213–215). The travelling laboratory is illustrated by eight photographs and the layout described with the aid of sketches. The various investigations which can be carried out in this laboratory are listed and the apparatus installed described. These include a wide range of chemical, physical and mechanical measurements.—R. J. W.

METALLOGRAPHY

Metallographic Examination of Defects in Malleable Iron. F. Boda. (*Kohászati Lapok*, 1952, **7**, Sept., *Öntöde*, 201–207). The metallographic examination of typical defects in white malleable iron, such as separation of graphite, porosity, cracks, tension cracks, shell formation, insufficient malleablizing absorption of S and defective machining is described.—P. K.

Mounting of Small and Irregular Shaped Specimens for Metallographic Examination. G. Vargha. (*Kohászati Lapok*, 1955, **10**, Nov., 496–497). A method is given for mounting small and irregular shaped specimens in a polymer "Spofacryl" for metallographic examination. "Spofacryl" can easily be turned and ground, and has a smooth, bright surface after polishing. It is heat resistant up to 100° C and not attacked by electrolytes or etchants. Mixed with aluminium, copper or iron powder it can be made conducting.—P. K.

Functions and Effects of Electrolytes Used in the Isolation of Carbides in Steels. N. Tietz, V. Toman and H. Tůma. (*Hutnické Listy*, 1957, **12**, (6), 517–521). [In Czech]. Some carbides are attacked by electrolytes used in separating them from the steel in which they occur. A study was made of the attack of various electrolytes on carbides of V, Mo, W, Ti, Zr, Ta and Cr, and tables showing the optimum compositions of electrolytes and the best working conditions were drawn up on the basis of these results.—P. F.

The Effect of the Particle Size of Segregated Flint Glass in Steel on the Results of Photometric Silicon Determination. W. A. Fischer and M. Wahlster. (*Arch. Eisenhüttenwesen*, 1957, **28**, July, 379–382). Samples were taken, at short intervals, from soft iron melts deoxidized with silicon. These samples contained primary flint glass precipitated in the melt immediately after the addition of Si, and secondary silicate inclusions which formed during the cooling process. The secondary inclusions were found to have a mean diameter from 2 to 4 microns, whereas the primary inclusions attained diameters from 10 to 15 microns.—L. J. L.

Carbides in Iron Alloys with High Chromium and Carbon Contents. H. Tůma, K. Löbl, and J. Ježek. (*Neue Hütte*, 1957, **2**, June 362–366). A study has been made of the structural changes occuring in three alloys with 3–4·5% C and 30% Cr during extended tempering at high temperatures. It was found that, in cast and quenched samples, mainly large acicular primary $(CrFe)_7C_3$-carbides are formed, and considerable amounts of $(CrFe)_{23}C_6$ carbides are segregated in the matrix after tempering at 550° C. It was shown from chemical analysis of the carbides, that the chromium, during tempering, invades the carbide phase from the matrix.—L. J. L.

Contributions to the Texture and Anisotropy of Cold-Rolled and Recrystallized Iron–Cobalt–Vanadium Alloys Containing 50% Cobalt. E. Houdremont, K. Janssen, G. Sommerkorn and H. Fahlenbrach. (*Tech. Mitt. Krupp*, 1957, **15**, No. 1, 13–22).

Lattice Distortion in Terminal Solid Solutions of the First Long Period Transition Metals and Copper. W. B. Pearson. (*Canad. J. Phys.*, 1957, **35**, Apr., 358–362). No correlation was found between solid solubility and lattice distortion for the metals with one another or with Cu.

On the Particles Inhibiting the Grain Growth of Al-killed Steel. II. Effect of Heat Treatment on the Austenite Grain Growth Behaviour. III. On the Fineness of Grain Size and Mechanism of Grain Coarsening. K. Endo and T. Otake. (*Nippon Kinzoku Gakkai-Si*, 1955, **19**, June, 389–392; 393–395). [In Japanese]. II. Studies were made of the grain growth within the γ-range of Al-killed fine-grained steels under various conditions of heat-treatment, time, temp. etc. The higher the AlN content, the more the grain growth is impeded at higher temperatures. This effect is enhanced by reduction of size of the AlN and improvement of its distribution by heat treatment. The effects of heat treatment are more pronounced if the specimen contains more AlN. III. It is shown that, to maintain the fine-grained structure, very small particles of AlN are needed, quantitatively $10–25 \times 10^{-4}$% at the maintenance temperature. If the equivalent nitrogen content falls to $1–5 \times 10^{-4}$% by solution in the matrix, a uniform coarse-grained structure in the steel results.—K. E. J.

Ferrite Networks. Some Effects in Plain Carbon Steel. K. J. Irvine and F. B. Pickering. (*Iron Steel*, 1957, **30**, June, 219–223). The embrittling effect of ferrite in tempered martensite

is reviewed. Cracking in medium carbon ingots is examined and illustrated and the conditions producing the defect were investigated. Crack initiation requires stress raisers such as nitride or sulphide inclusions. Heat treatments correcting the effect are suggested.

Application of a Dilatometer of Short Gauge Length to the Investigation of Transformation Processes. W. Hofmann and R. Müller. (*Z. Metallkunde*, 1957, **48**, Mar., 104–108). In order to study the transformations in steel during welding, a self-recording dilatometer was developed, having a gauge length of 2·5 mm. with thermocouple measuring tips. The construction of the instrument is described, with its application to various steels.—L. D. H.

Stabilization of Austenite at Temperatures above the Range of Martensite Transformation. K. A. Malyshev, N. A. Borodina and V. A. Mirmel'shtein. (*Fizika Metallov i Metallovedenie*, 1956, **2**, (2), 277–284). [In Russian]. Results of investigations of the influence of isothermal treatment at temperatures above the beginning of martensite transformation and the influence of phase work-hardening during direct and reverse martensite transformation on the stabilization of austenite are described.—V. G.

The Effect of Elements Forming Stable Carbon Compounds on the Isothermic Change of Supercooled Austenite. H. Matyja. (*Hutnik*, 1956, **23**, (7–8), 285–290). [In Polish]. Topics discussed by the author include: the effect of alloying elements on the graphs relating time, temperature, and pressure; application of the theory of crystallization to the isothermic transformation of austenite; the effects of the alloying elements with reference to those changes. The isothermic transformations of two different steels containing Mn (0·86% and 0·88%), Cr (1·19% and 1·22%), Ni (3·98% and 3·93%) and Ti (0·11% and 0·42%) were investigated experimentally. One conclusion is that the effect of Ti on the stability of austenite at the temperature of its formation (975° C) is connected with the presence of Cr and Ni.—K. G.

Decomposition of Austenite to an α-Phase Under the Influence of Latent Constraints in 18-8 Type Stainless Steels. P. Bastien and G. Stora. (Note by A. Portevin). (*Compt. Rend.*, 1957, **244**, May 20, 2613–2616). Needles are formed at an easily measurable rate in unstable austenite under strains due to quenching or transformations in controlled solution. The note points out the resemblance of the structure figured to bainitic Ar″.

The Significance of Carbide Solubility for Austenite Formation Characteristics of Tool Steels. A. Rose and L. Rademacher. (*Stahl u. Eisen*, 1957, **77**, Apr. 4, 409–421). The quantity of austenite in steels depends on their composition, their heat-treatment and the holding time. Austenite formation in tool steels takes place in the heterogeneous phase austenite + carbide. The relation between austenite formation and transformation characteristics is illustrated by a number of *TTT* diagrams, which are discussed in detail. Carbide precipitation occurring at higher temperatures of austenite formation disturbs the equilibrium of austenite and leads to martensite formation mainly in the vicinity of the grain boundaries, which subsequently become impoverished in carbon and alloying elements.—T. G.

The Use of Microanalytical Methods in Studies of the Isothermal Decomposition of Austenite. (Part I. Formation of Nuclei and the Growth of the New Phase). J. Čadek and K. Mazanec. (*Hutnické Listy*, 1957, **12**, (3), 216–222). [In Czech]. Recent theories relating to homogeneous and heterogeneous nucleation in solids are surveyed, and their suitability for dealing with metallurgical problems such as the nucleation of new phases is discussed.—P. F.

Effect of Variations in Austenite Composition on the Thermal Transformation of Martensite in Steels with 18% Chromium and 2·4 or 6% Nickel. P. Bastien and A. Sulmont. (*Compt. Rend.*, 1957, **244**, June 17, 3056–3059). Dilatometric determination of the shift of the M_s point is reported. Heating to 1000° and cooling at 280°/h gave the M_s point at 100° for a 18% Cr, 6% Ni, 0·05% C steel, with about 90% martensite. The effects of repeated cycles of heating to 1000° and cooling at 160°/hr are plotted, when the composition of the austenite was very variable.

An Investigation of the Structure of Steels 30KhMA and KH(8HKH-15) after the Intermediate Transformation. L. S. Palatnik and B. A. Leont'ev. (*Fizika Metallov i Metallovedenie*, 1956, **2**, (1), 43–53). [In Russian]. Results of metallographic and electron microscopical investigations of the structures of the above steels (chemical composition given) formed in the intermediate range are shown and an explanation of the mechanism of the intermediate transformation in the above steels is proposed.—V. G.

Continuous Distributions of Dislocations: Surface Dislocations and the Crystallography of Martensitic Transformations. R. Bullough and B. A. Bilby. (*Proc. Phys. Soc.*, 1956, **69B**, Dec. 1, 1276–1286). The surface dislocation forming the boundary between the phases is assumed to correspond to one parallel array of like dislocations of arbitrary Burgers vector moving in an arbitrary plane and the vector and plane are assumed given. The theory is applied to deduce habit plane, shape deformation and orientation relationship. Other similar treatments are also considered.

The Influence of Phase Work-Hardening on the Position of Martensite Points of a High Speed Cutting Steel. P. M. Yushkevich. (*Fizika Metallov i Metallovedenie*, 1956, **2**, (1), 54–56). [In Russian]. The influence of tempering temperature (540, 560, 580, and 620° C), number of one-hourly tempering treatments and the amount of martensite on the temperature of the beginning of martensite transformation was studied. The steel contained 1·5% carbon, and magnetometric and X-ray methods were used in the investigation.—V. G.

Computation of M_s for Stainless Steels. F. C. Monkman, F. B. Cuff jun. and N. J. Grant. (*Metal Progress*, 1957, **71**, Apr., 94–96). A new attempt has been made to derive a linear relationship between the M_s temperature and composition in nickel-bearing stainless steels. The relationship derived shows a small improvement over published equations. Because of the complex interaction of alloying elements any further improvement by first-order equations is not to be expected.

Studies of the Delta-Ferrite Transformation in High-Titanium 18/9 Stainless Steels. V. Číhal and M. Přázak. (*Hutnické Listy*, 1957, **12**, (3), 236–242). [In Czech]. Results are given of electron-micrographic and polarization experiments on the passivation of the steels. Delta ferrite was found to decompose into carbide and sigma- and gamma-phases. The presence of σ-phase reduces the ability of the steel to undergo secondary passivation, and affects the polarization potentials outside the region of passivation.—P. F.

Contribution to the Significance of the K-State of Resistance Alloys. H. G. Müller and H. A. Schulze. (*Z. Metallkunde*, 1957, **48**, Feb., 72–79). Homogeneous Ni–Fe–Cr alloys, having a Ni–Cr ratio of 4 : 1, were subjected to very severe cold working, and showed a large increase in the room temperature resistance in the K-state. This effect, together with similar phenomena in other alloys, was investigated by X-rays and electrical conductivity measurements. The formation of the K-state was found to be accompanied by a lattice contraction, which is proportional to the variations in resistance.—L. D. H.

Choice of the Iron–Carbon Constitution. Z. Jasiewicz. (*Hutnik*, 1956, **23**, (7–8), 270–276). [In Polish]. The author gives a critical review of theoretical methods of discrimination of phase equilibria of the system Fe–C. The lack of agreement between the theory and experimental results can be obviated by introducing corrections to the experimental data. The corrections are calculated from thermodynamic equations, graphical integrations, simplifications and extrapolations.—K. G.

The Names of Structures of the Iron–Carbon Systems. T. Malkiewicz. (*Hutnik*, 1956, **23**, (7–8), 283–285). [In Polish]. Since in the light of the modern science, the old names of various crystalline structures of the Fe–C system have become obsolete, the author proposes new ones (i.e. spheroidal pearlite change to spheroidal cementite). Definitions of corresponding critical temperatures are also given.—K. G.

Reasons for Unsatisfactory Ductility of Iron–Chromium Aluminium Resistance Alloys. A. P. Boyarinova and S. I. Malov. (*Stal'*, 1957, (3), 280). [In Russian]. From studies of the structure, nonmetallic inclusions and hardness of Fe–Cr–Al alloys the author attributes poor ductility mainly to the presence of large quantities of Al_2O_3-type inclusions. Methods of improving ductility are briefly considered.—S. K.

Metallographic Examination of Large Inclusions in Steel. Z. Hegedüs. (*Kohászati Lapok*, 1956, **11**, April, 165–172). The macro inclusions in steel originate from slag in the furnace or ladle or from refractories or hot topping compounds. The chemical and mineralogical composition and physical characteristics of these inclusions as well as the methods of their metallographical examination are given.—P. K.

The Crystallization of Graphite in Cast Iron. I. Karsay. (*Kohászati Lapok*, 1955, **10**, *Öntöde*, Aug. 169–176; Sept., 205–209). The author reviews comprehensively the various theories of the formation of lamellar, flaky and globular graphite. Afterwards he refers to a new hypothesis of the formation of "globe shell" graphite, based on his experiments and investigations.—P. K.

Analysis by Combined Impedance and Dilatometry of Transformations in Metals and Alloys. H. Guyot. (*Recherche Aéronaut.*, 1957, Mar.-Apr., 51–57). Apparatus for simultaneous analysis is described. Interpretation of the values is discussed and examples of a non-ferromagnetic refractory alloy and of the allotropic transformation of Co are given.

The Use of Diagrams of the Anisothermal Decomposition of Austenite in Studies of the Thermal Kinetics of Arc-Welding. A. Havalda. (*Zváranie*, 1957, **6**, (6), 163–166). [In Slovak]. Time-temperature-composition diagrams were constructed for a range of cooling rates important in open-arc welding of two steels containing 0·97% and 0·79% Cr respectively, and various small amounts of Ni, Cu, Mo etc. The use of such diagrams in practice is explained.—P. F.

A Re-examination of the Growth of Martensite in a 1·5% Carbon, 5% Nickel Steel. R. Priestner and S. G. Glover. (*Acta Met.*, 1957, **5**, Sept., 536–538). Austenized and quenched material, after removal of the decarburized layer and electropolishing, produces light-etching rims at 100–350° C. These rims darken on ageing and are considered to be martensitic and not to be formed at the ageing temperature.

The Metallography of Low-carbon Bainitic Steels. K. J. Irvine and F. B. Pickering. (*J.I.S.I.*, 1958, Feb., **188**, 101–112). [This issue].

The Effect of Tungsten Content on the Kinetics of Formation of Hypoeutectoid Ferrite. K. Mazanec and J. Čádek. (*Hutnické Listy*, 1957, **12**, (6), 494–499). [In Czech]. The effect of W content on the rate of nucleation N and on the rate of growth G of nuclei of hypoeutectoid ferrite was studied in two steels, each containing 0·4%C, the W contents being 0·54 and 1·58% respectively. The results showed that (*a*) in the range 675–745° C N decreases with increasing W addition independently of the temperature. The value of G is considerably depressed by W additions below about 650° C, but not affected above about 745° C. (*b*) With large degrees of supercooling N is controlled by the rate of diffusion of C in austenite, which has an activation energy of 33 kcal/mole; with small degrees of supercooling N is controlled by the rate of formation of lamellar nuclei. The rate of formation of the nuclei, N, at low degrees of supercooling is probably reduced as the result of the effect of W on the surface energy at the gamma-phase grain boundaries; the effect of W on the surface energy of the austenite–ferrite interfaces is probably small. (*c*) The dependence of N on time was studied. N increases rapidly after an incubation period, reaches a maximum, and again declines, obeying a hyperbolic law, i.e. the product NT is constant, where T is the time. (*d*) The statistical metallographic method used for the determination of N gave results which agreed well with N as determined from the mean rate of growth of ferrite particles.—P. F.

Investigation of the Isothermal Transformation of Copper–Chromium and Nickel–Chromium Cast Iron with 0·5% Molybdenum. A. De Sy and J. van Eeghem. (*Giesserei*, 1957, **44**, Apr. 11., 189–199). The compositions of the cast irons investigated are first described. These contain up to 0·25% Cr, 2% Cu and 2% Ni. The determination of the TTT curves for these alloys is described and the results obtained are given and interpreted. The influence of the alloying additions individually and together is examined. Their effect on the texture is illustrated in 15 micrographs.—R. J. W.

The Development of Structure Diagrams of Cast Irons. M. Skala. (*Slévárenství*, 1957, **5**, (5), 129–135). [In Czech]. The author discusses degrees of 'eutecticity' and graphitization in cast irons. Existing structure diagrams of cast irons are all to some extent imperfect, as numerous problems connected with graphitization are as yet unsolved. The best diagrams are considered to be those proposed by Uhlitch, Laplanche, and Girshovitch.—P. F.

CORROSION

Corrosion Research—The Corrosion of Metals Group of the Chemical Research Laboratory. Chemical Research Laboratory. (*Corrosion Prevention and Control*, 1957, **4**, July, 49–51). Work on immersed corrosion using tracer elements is presented, especially on the effect of inhibitors. Boiler tube corrosion is then discussed including work on plastic-coated mild steel discs under simulated conditions. The article is derived from a report from the laboratory.

The Electrochemical Basis of Corrosion. J. Brenet. (*Corrosion et Anticorrosion*, 1956, **4**, Oct.-Nov., 317–329). An account of the thermodynamical and kinetic principles of electrochemistry is given and extended to the phenomena of corrosion. The formulation of Audubert is shown and the importance of pH is discussed, and a general chemical formulation is put forward, evaluated and exemplified. (20 references).

Should the Origin of the Hypothesis for the Electrochemical Principles of Corrosion be Attributed to the French Chemist. L.-J. Thénard? M. Weil and P. M. Delaunay. (*Corrosion et Anti-Corrosion*, 1956, **4**, Oct.-Nov., 330–331). The claims of Thénard (1777–1857) and La Rive, especially the authorship of an anonymous paper in 1819, are discussed.

Oxidation of Alloys at Elevated Temperatures. G. Castro Fariñas. (*Inst. Hierro Acero*, 1957, **10**, Jan.-Mar., 11–19). [In Spanish]. A brief review of the heat-resisting steels is given. In addition to an account of the mechanism of the oxidation of iron, details of the effects of corrosive gases and surface treatments upon the oxidation resistance of these steels is also included. (18 references).—P. S.

Oxidation Tests at the Thermal Balance of Certain Al and Cr Bearing Cast Irons. N. Collari and E. Hugony. (*Met. Ital.*, 1957, **49**, May, 341–347). [In Italian]. The behaviour of samples of normal Cr, Al–Cr and high Al-bearing cast irons is studied on the thermal balance by heating them up to 800° C in air for 3 h. The authors show that (i) in normal or low-alloy cast irons, in Al–Cr cast iron and in heat-resisting steel a weight increase can be detected whilst a loss in weight occurs with grey irons (graphitic) containing Al and showing resistance to oxidation—this it is claimed is due to the surface oxidation of the carbon; (ii) Al gives a higher hot resistance than chrome.—M. D. J. B.

Corrosion Fatigue. T. D. Weaver. (*Chem. Ind.*, 1957, Sept. 7, 1190–1194). Methods of testing, the mechanism of corrosion fatigue, resistance of various materials and surface protection are reviewed. Breaking of surface films is the important factor.

An Experimental Study of Fretting. I-Ming Feng and B. G. Rightmire. (*Proc. Inst. Mech. Eng.*, 1956, **170**, (34), 1055–1064). A method for the visual observation of the fretting process is described. Studies in air, CO_2 and He are reported supporting the mechanism previously put forward. It appears that chemical reactions such as oxidation take place during or after removal of metal from the surface.

Underground Steel Pipelines. (*Corrosion et Anti-Corrosion*, 1956, **4**, Oct.-Nov., Supplement, *Tubes et Conduites*, **1**, Nov., 9–10). A brief account of French steel pipes and their protection.

The Protection against Corrosion of High Tension Cables in Steel Tubing under Fluid Pressure. J. Changarnier and J. Rollin. (*Corrosion et Anti-Corrosion*, 1957, **5**, Jan. 2–9). Cathodic protection systems are described.

New Methods for the Protection of Low Pressure Air Lines and Shaft Installations Against Corrosion. F. Eisenstecken. (*Glückauf*, 1957, **93**, July 6, 832–838). Trials have shown that the air produced at low pressure in a turbo-compressor still contains reactive constituents after direct or indirect cooling. Methods adopted to protect the inner surfaces include passivation and various types of protective coatings.—L. D. H.

Combatting Corrosion in a Pulp Mill with Stainless Steel. J. Kolberg. (*Chem. Eng. Prog.*, 1957, **53**, July, 353–356). Corrosion troubles due to unusually high chloride content were observed and improper heat treatment, stresses from fabricating processes and improper design all contributed under these conditions. Intergranular corrosion, pitting and crevicing, effects of stress and fatigue and weld failures are reviewed. A new specification for a suitable steel is given.

Discussion of the Fight Against Corrosion. D. Pétrocokino and J. Frasch. (*Corrosion et Anti-Corrosion*, 1956, **4**, July-Aug., 246–251). A diagram for the corrosion of steel showing the zone of passivation and the theory of cathodic protection are indicated. Factors involved are tabulated, and the conditions under an adherent water-drop are indicated. Notes on inhibitors follow.

Sodium Polyphosphates and their Use as Corrosion Inhibitors. A. Indelli. (*Met. Ital.*, 1957, **49**, May, 333–340). [In Italian]. The sodium salts of condensed phosphoric acids differ from

most other similar compounds because of their characteristic thermodynamic metastability accompanied by chemical inertia which prevents their rapid return to simple phosphates. Some of these salts show a low molecular weight and are crystalline, others have a very high molecular weight and are colloidal. Between these two extremes there is a full range of compounds which show intermediate properties. The inhibiting action of these compounds on steel corrosion needs the presence of O_2 and Ca ions of the metal surface. The presence of a protective layer is revealed by interference colours. (33 references).—M. D. J. B.

Anti-rust Protection by Means of Metallic Pigments. A. Pollack. (*Metall*, 1957, **11**, June, 506–508). This is a brief survey of recent literature (1951–1956) concerning the use and method of application of rust-preventive metallic pigments.

V.P.I. Paper, Advantageous Packing against Metallic Corrosion. A. Isla Garcia. (*Tecn. Met.*, 1955, **11**, Nov.-Dec., 214–223). [In Spanish]. The properties and applications of this protective paper are described and illustrated. (25 references).—P. S.

Cathodic Protection. L. B. Hogben, K. A. Spencer and P. W. Heselgrave. (*Proc. Inst. Elect. Eng.*, 1957, **104A**, Aug., 307–319). Corrosion theory is outlined and an account is given of sacrificial anodes and power-impressed currents. Potential measurement is considered in detail and determination of soil resistivity. Uses and economics are reviewed.

Case History on Cathodic Protection. (*Steel*, 1957, **141**, Aug. 12, 128–129). An example of the application of a cathodic protection system to underground pipework is described.—D. L. C. P.

ANALYSIS

Recent Developments in Photoelectric Colorimetry. The Determination of Phosphorus, Tungsten, Silicon, Nickel, and Boron in Steels. E. Piper and H. Hagedorn. (*Arch. Eisenhüttenwesen*, 1957, **28**, July, 373–377). Trends of development in colorimetric methods are outlined. Improvements in procedure are described, and detailed working instructions are given.—L. J. L.

The Determination of Silicon in Steel and Cast Iron by Means of the New Filter and Combustion Tubes. G. Lingelbach. (*Giessereitechn.*, 1957, **3**, June, 133–134). Apparatus and method are briefly described. Its applicability is critically discussed. The method is ideally suited for laboratories carrying out up to 6 analyses per day. For larger numbers of Si determinations in cast iron the standard methods (evaporation or gelatine) are as good.—L. J. L.

The Routine Determination of Oxygen in Steel Using a Carrier Gas Fusion Technique. C. E. A. Shanahan and F. Cooke. (*J.I.S.I.*, 1958, Feb., **188**, 138–142). [This issue].

An Apparatus for Measurement of the Occlusion of Hydrogen by Metals. M. Kotyk, J. K. Magor and H. M. Davis. (*Metallurgia*, 1957, **56**, Sept., 153–155). Apparatus for the equilibration of metal specimens in a hydrogen atmosphere is described. Comparison with a glass specimen enables the amount occluded to be determined.

The Effect of Nitrides in Silicon Iron on the Determination of Oxygen by Chlorination, and the Possible Direct Determination of Ammonium Nitride. F. J. Armson and H. L. Bennett. (*J.I.S.I.*, 1958, Feb., **188**, 132–137). [This issue].

Rapid Analysis of Chromium and Vanadium in Steels. I. Sajo. (*Kohászati Lapok*, 1952, **7**, June 143–144). A titrimetric method for the rapid determination of Cr and V in steels is described. It is based on the oxidation of the sample with $KMnO_4$.—P. K.

Determination of Low Percentages of Cobalt in Ferrous Materials. J. R. Rait and J. L. West. (*Chem. Ind.*, 1957, Sept. 7, 1204). A letter. A colorimetric method for small quantities in steel to $\pm$ 0·001% is outlined.

Photometric Determination of Molybdenum in Tungsten Ores. P. G. Jeffery. (*Analyst*, 1957, **82**, Aug., 558–563). Toluene–3 : 4–dithiol in presence of citric acid is used.

The Separation of Uranium from Large Amounts of Iron and Aluminium by Anion Exchange in Nitrate Media. H. M. Ockenden and J. K. Foreman. (*Analyst*, 1957, **82**, Aug., 592–593). De-Acidite FF columns are used.

The Determination of Lead in Free-Cutting Steels. I. Bozsai and K. Szabados. (*Kohászati Lapok*, 1955, **10**, Sept., 423–424). A method is given for determination of the lead content in leaded free-cutting steels. It is based on precipitation as molybdate.—P. K.

Magnesium Analysis in Grey Cast Iron. I. Sajo and P. Repas. (*Kohászati Lapok*, 1953, **8**, Nov., 225). The authors describe a complexometric and a photometric method.—P. K.

The Determination of Antimony in Cast Iron. R. C. Rooney. (*Analyst*, 1957, **82**, Sept., 619–623). Sb is determined separately in the graphite–silica residue and in the HNO_3 solution. The measurements are made by spectrophotometer.

Methods of Rapid Determination of Silicon in Ferrosilicon. S. Velken. (*J.I.S.I.*, 1958, Feb., **188**, 119–121). [This issue].

Residual Analysis of Cast Iron and Pig Iron. A. Wittmoser and W. D. Graa. (*Giesserei*, 1957, **44**, Apr. 25, 254–257). The experimental arrangement for the residual analysis of steels is compared with that for cast iron. This consists of a special type of electrolytic cell in which the specimen forms the cathode. The magnetic separation of cementite and a flotation method for separating graphite from oxide are also described and illustrated. The isolated fractions are examined microscopically. (23 references).—R. J. W.

Fifth Spectrochemical Seminar of the Italian Association for Metallurgy. (*Met. Ital.*, 1957, **49**, June, 399–487). **Principles, Methods and Apparatus for Emission Spectral Analysis.** J. Junkes. (399–404). **The Development of Spectrochemical Analysis in the Laboratory and in Industry in the last Decade and the Work of the C.R.S.** O. Masi. (405–408). **Some Particular Applications of Emission Spectrography.** E. Locuille. (409–410). [In French]. **Testpieces and Their Selection for Spectrographic Analysis.** H. Guyer. (411–414). [In French]. **Normal and Abnormal Spectroscopic Inhibitions and Sensitized Emissions.** M. Pierucci. (415–418). **Enhancement and Attenuation in Spectrochemical Analysis in Relation to the Light Source and Excitation Potentials of the Spectral Lines. Analytical Deductions.** V. Gazzi. (419–424). **Photographic Photometry.** J. Junkes and E. W. Salpeter. (425–430). **Effective Line Widths for Determinations of Intensity.** R. Intonti, H. Pfundt and A. Lais. (431—443). **Blackening and Effective Line Width.** R. Passeri. (444–448). **The Use of the Spectrograph in Blast-Furnace Control. 1. Analysis of Slag and Sintered Ore.** B. Sommacal and A. Porta. (449–456). **An Internal Calibration Method Applied to the Spectrographic Analysis of Steels.** B. Morello. (457–461). Mn, Si, Cr, Ni, Mo, V and Cu are determined for various C contents. **The "CF4-Optica" Spectrophotometer.** B. Polli. (462–464). **New Equipment for Direct-Reading Analysis.** H. Bückert and I. Raffaele. (475–478). **Comparison of Successive-Integration and Parallel-Integration Quantometers for Spectrochemical Analysis.** M. Scalise. (479–482). **The Complementary Nature of X-Ray Fluorescence and Optical-Emission Methods of Spectrochemical Analysis.** M. Scalise. (483–487).

The Effect of Structural Condition on the Results of Spectrographic Steel Analysis. G. Brucelle. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Metallurgiques*, 18th *Congress*, 1955, 183–190). It is found that heat treatment is practically without influence or spectrochemical analysis.

Corrosion Mechanisms in the Plain Can. E. L. Koehler and C. M. Canonico. (*Corrosion*, 1957, **13**, Apr., 227–237). Factors affecting the corrosion of tinplate in prune juice and peaches have been investigated. Results of tests on black plate taking into account "pickle-lag," tinplate and steel–tin couples are reported showing H_2 evolution, amounts of tin and steel dissolved, potential relationships, protective currents and polarization characteristics. The shelf life of a tin can containing fruit juice is envisaged as made up of three stages; (i) When no steel is exposed and only dissolution of tin takes place, (ii) When both steel and tin are exposed and (iii) when the tin has completely dissolved. The first two stages are the most important.—J. F. S.

Oxidation of Steel in Superheated Steam. P. Gröbner and Z. Bret. (*Hutnické Listy*, 1957, **12**, (2), 125–131). [In Czech]. On the basis of experiments carried out by the authors it is shown that Wagner's theory of oxidation can be applied with sufficient accuracy for practical purposes to ferritic steels containing various amounts of Cr, Ni, Mo, V, W, and Cu. The temperatures ranged from 400 to 800° C. The results are compared with data obtained by other investigators; on the whole satisfactory agreement was obtained.—P. F.

Oxidation of Metals: Determination of Activation Energies. P. Kofstad. (*Nature*, 1957, **179**, June 29, 1362–1363). A

method of calculation is shown for temperature dependence and compared with data for Ti, Ni, Zr, and Cu.

High Temperature Oxidation of Metals and Alloys. P. Kofstad. (*Tek. Ukeblad*, 1957, **104**, Mar. 21, 225–230). This is the first part of an article which presents the modern theories of the oxidation of metals and alloys at elevated temperatures (above 500° C). The mechanism of the oxidation of Fe in oxygen to FeO,Fe_2O_3, and Fe_3O_4 at high temperatures is discussed.—L. D. H.

On the Resorption of Discontinuities of Ferrous Oxide During Oxidation of Iron at High Temperatures. M. Cagnet and J. Moreau. (*Compt. Rend.*, 1957, **244**, June 12, 2925–2928). The conditions of diffusion between iron-rich and oxygen-rich lattices with reference to ferrous and ferric ions are considered. Observations on grain boundaries are illustrated.

Influence of the Purity and Structure of the Metal on Intergranular Diffusion of Oxygen in Iron. R. Sifferlen and C. Bourelier. (*Compt. Rend.*, 1957, **244**, June 12, 2928–2929). Iron oxidized at 850° for 1 h in a mixture of H_2/H_2O vapour has been examined on polished sections. With electrolytic iron after several days in H_2 at 880° no oxide inclusions are seen in the grains or at the boundaries but if the metal is deformed (by a 6% extension for example) oxide inclusions appear along the grain boundaries. No inclusions are formed at the boundaries or at the polygonization joints with iron purified by zone melting.

On the Resistance to Intercrystalline Corrosion of Welded Seams from Stainless Steels of 18–8 Type. B. I. Medovar. (*Avtom. Svarka*, 1951, **4**, (3) [18], 22–51). [In Russian]. On the basis of experimental evidence it is suggested that the main cause of the tendency of welded seams of 18–8 type to intercrystalline corrosion is the separation from austenite of the ferrite component rich in chromium and absence of the formation of chromium carbides. Due to the ferrite component and a complicated stressed state, the diffusion of chromium in welded seams is faster than in rolled steel of the same composition. It was experimentally shown that, in addition to titanium and niobium, other ferrite forming admixtures produce a high resistance of welded seams to intercrystalline corrosion. Al, Si, V, W and Mo are such additions. An increase in the concentration of chromium is also an effective factor. As niobium causes hot cracks and titanium is strongly oxidized during welding it is proposed to alloy seams of 18–8 with silicon, vanadium and other elements in order to increase their resistance to intercrystalline corrosion.—V. G.

A Potentiostat Technique for Studying the Acid Resistance of Alloy Steels. C. Edeleanu. (*J.I.S.I.*, 1958, Feb., **188**, 122–132). [This issue].

The Resistance to Corrosion of Welded Joints from Chromium–Nickel Stainless Steel in Boiling Nitric Acid. B. I. Medovar and N. A. Langer. (*Avtom. Svarka*, 1951, **4**, (4), [19], 73–81). [In Russian]. Results of investigations of the corrosion resistance of welded specimens from stainless steel (IX18N9T) are described. Welding was carried out under flux with 18–8 and 25–20 electrodes. It was established that welds with two-phase austenite–ferrite structure are more resistant to boiling 65% nitric acid than specimens with purely austenitic welds.—V. G.

The Attack by Zinc Melts Saturated with Iron on Iron Containing Carbon, Sulphur and Phosphorus. D. Horstmann. (*Forsch. Wirts. Nordrhein-Westfalen*, 1957, No. 367, pp. 42). Losses of weight of iron, and microstructures of various steels before and after contact with the melts are given, especially the alloy layers formed. The form of the curve at high or low temperatures is parabolic. In between (495–515°) it is practically linear for soft irons. With higher C content the range narrows. Effects on pearlite and troostite are noted and also martensite, the attack being only slightly greater. S has a small and P a large effect.

Velocities of Corrosion Processes. W. Katz. (*Metalloberfläche*, 1957, **11**, May, 145–154). Working hypotheses are derived to account for the corrosion rates obtained in experiments described in the literature, and carried out by the author. Examples of attack, with and without the formation of protective layers, include the corrosion of iron in sodium sulphate solution, the use of passivators for iron, and other ferrous applications.—L. D. H.

The Corrosion Resistance of Ductile Iron in Sea Water and Petroleum Tanker Services. M. Paris and B. de la Bruniere. (*Corrosion*, 1957, **13**, May, 292–296). Tests on nodular iron are described and durabilities of pipes and losses of weight of nodular and grey iron and steel under various conditions are reported. Iron containing 1·5% Ni is satisfactory in tankers carrying Middle East oil. Otherwise the corrosion rates of ductile and grey irons are very similar in all media examined.

Chemical Treatment of Feed Water for Boilers. G. Bianucci. (*Calore*, 1957, **28**, Jan., 3–18). [In Italian]. After discussing the effects of furring, corrosion and wear in pipes, the author describes various methods of treating water and comments on their merits. (19 References).—M. D. J. B.

Measurement of Instantaneous Corrosion Rate by means of Polarisation Data. R. V. Skold and T. E. Larson. (*Corrosion*, 1957, **13**, Feb., 139t–148t). Steel and cast iron were tested in 3000 ohm/cm waters and potential-time studies were made for correlation with corrosion rate. A limited empirical relationship was found between polarization slope at low c.d. and weight loss. The effect of pH is considered briefly.

Analysis of Corrosion Pitting by Extreme-Value Statistics and its Application to Oil Well Tubing Caliper Surveys. G. G. Eldredge. (*Corrosion*, 1957, **13**, Jan., 51–60). A detailed account is given of how extreme-value statistics can be applied to the analysis of the depths of corrosion pits. Caliper surveys of pits in oil well tubing are used to illustrate the method. Expectations of deep pits and of perforation can be extrapolated in ways shown. A special graphical presentation of pit depths on a " pit depth rank chart " has been developed for use for tubing strings.—J. F. S.

Electrical Resistance Corrosion Measurements Employing Alternating Current. W. L. Denman. (*Corrosion*, 1957, **13**, Jan., 43–50). An electrical resistance method employing alternating current for measuring corrosion rates, has been developed for use with thin metal stripe or wires. The method is shown to be applicable to inhibitor tests in distilled water at room temperatures, closed recirculating tap water above 170° F, flowing return line condensate and possibly tubular material in service.—J. F. S.

Control of Corrosion Resistance By Tests with Salt Spray. L. Richard. (*Galvano*, 1956, **25**, Oct., 24–25; Nov., 45–46). An accelerated corrosion test apparatus is described using ½–3 cm^3 per 80 cm^2 per h for 16 h or more of 20% NaCl solution. The spraying device is worked by compressed air.

Corrosion Measurements in a Hydrogen Sulphide–Water Absorption Pilot Plant. B. W. Bradley and N. R. Dunne. (*Corrosion*, 1957, **13**, Apr., 238–242). Corrosion tests were conducted in a pilot plant for sweetening very sour natural gas containing about 45% acid gases by water absorption. Carbon steel corrosion rates were very high at first but became tolerable after a 19-day test. Killed carbon steel, type 304 stainless steel, Inconel and K-Monel were resistant to sulphide stress-corrosion cracking. A water dispersible amine type inhibitor reduced corrosion and protected carbon steel from stress corrosion. Recommendations for materials for use in service are made, including types 304 and 316 stainless steel.—J. F. S.

Evaluation of Laboratory Testing Technique for Cooling Water Corrosion Inhibitors. Task Group T–5C–1 on Corrosion by Cooling Waters. (*Corrosion*, 1957, **13**, May, 345–346). Tests on corrosion by river water and the effects of inhibitors were made by 4 methods. The dynamic flow test was found the most accurate for recirculated systems and the static test was suitable for storage.

Selection of Rust Inhibitors to Meet Service Requirements. A. J. Freedman, A. Dravnieks, W. B. Hirschmann and R. S. Cheney. (*Corrosion*, 1957, **13**, Feb., 89t–94t). The effectiveness of inhibitors depends upon the conditions met with in service. Testing should reproduce or simulate these. Methods for flowing static or condensation conditions and a new procedure based on the Indiana Conductometric test gives quantitative measurements at low corrosion rates and will detect small differences in performance.

The Influence of Inhibitors and Wetting Agents on the Corrosion of Iron in Dilute Sulphuric Acid. W. Machu and S. El Gendi. (*Metalloberfläche*, 1957, **11**, Apr., 135–139). Experiments with wetting agents in dilute sulphuric acid showed that the agents investigated had a certain inhibiting action, which disappeared at increased temperatures. The effect of wetting agents in the presence of inhibitors was investigated at various temperatures. The work on the temperature effect of wetting agents showed that the action was one of purely physical adsorption, whilst that of inhibitors is based on chemisorption.—L. D. H.

The Determination of Sulphur in Metals by Low-Tension Spark. W. Koehler. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Metallurgiques, 18th Congress*, 1955, 215–223). Silver electrodes were adopted after Al had been tried, and Pd alloys and steels were examined. The limit of determination is ~ 0·3% S.

Study of the Analysis of Carbon, Sulphur and Phosphorus in Steels by Far Ultra-Violet Spectrography. J. Romand and G. Balloffet. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Metallurgiques, 18th Congress*, 1955, 191–213). The characteristic wave lengths and ionization potentials are given and the method described with illustrations of apparatus, circuits and spectra.

Extraction and Flame Spectrophotometric Determination of Chromium. H. A. Bryan and J. A. Dean. (*Anal. Chem.*, 1957, **29**, Sept., 1289–1292). Chromic chloride is extracted from N HCl with 4-methyl-2-pentanone and determined directly in an oxyacetylene flame. Iron is also extracted but does not interfere. As little as 0·18 Cr/Ml can be estimated accurately.

Spectrographic and Colorimetric Analysis of Carbides isolated from a Chrome Steel. F. Sussmann. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Metallurgiques, 18th Congress*, 1955, 41–75). The method is described at length and the reasons for its choice, photographic blackening and the rays used are also considered. Simultaneous determination of Cr and Mn is described and spectrophotometric results are compared. The analyses varied between 40–90% Fe, 1·5–15% Cr and 0·25–2% Mn.

Use of a Spectrochemical Method of Analysis for Determination of Traces of Elements in Steels. A. Laurent. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Metallurgiques, 18th Congress*, 1955, 77–95). A method is described in detail and its application to Ni is shown, it will also serve for Al and for Mn, Cr, Mo, V, Ti, Cu and Pb. The sample is dissolved and some drops are dried off on a graphite electrode and excited with an intermittent arc.

Analysis of Stainless Steels With the ARL X-Ray Quantometer. W. H. Barry. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographiques des Produits Metallurgiques, 18th Congress*, 1955, 297–304). The apparatus is described, first developed for the Al industry. Its reproducibility is of the order of 0·2%. Chemical and spectrographic values for Fe, Cr, Ni, Mn and Mo are compared.

Principles of Measurements and Instruments for Nuclear Radiations. H. Peter. (*Metall*, 1957, **11**, July, 586–593). Following a description of the scintillation and electrical methods for the detection of nuclear radiations, recently marketed American and German instruments are described and their uses indicated.—J. G. W.

INDUSTRIAL USES AND APPLICATIONS

Alloy and Special Steels in Railway Work. H. O'Neill. (*Metallurgia*, 1957, **56**, Aug., 74–76). Materials for locomotives, moving parts, drawgear, springs, tires, rails, carriages and wagons are briefly reviewed.

Lightweight Steel Construction as a Technical Advance in Pit Supports. E. Dörtelmann, H.-J. Hülsebeck and O. Jacobi. (*Glückauf*, 1957, **93**, 22 June, 737–751). The advantages to be gained by the use of lightweight steel pit props instead of aluminium alloy are discussed. Provided the steel has suitable physical properties, it is shown that the original cost and saving in labour offer substantial advantages. Examples from practice are given, with some details of specification and design.—L. D. H.

Special Steels Used in Machinery for the Iron Mines. (*Aciers Fins Spec. Franç.*, 1957, July, 30–53; In English, 36–42). Brief descriptions of drilling machines, scraper loaders, continuous loaders, shuttle wagons and underground locomotives are given with an account of the steel used for the various parts, thus for the wagons, tangent screw reducers, disc clutches, rake conveyors and cable guides are considered.

Tool Steels for the Moulding of Plastics. C. C. Hanson. (*Metallurgia*, 1957, **56**, Sept., 109–114). Steels for moulds require machinability, heat treatment reliability, cleanliness, resistance to deformation and wear, staining and corrosion. Hobbing and carburizing and oil and air hardening grades are then reviewed.

Creep, Stress-Relaxation and Metallurgical Properties of Steels for Steam Power Plant Operating with Steam Temperatures above 950° F. A. I. Smith, E. A. Jenkinson, D. J. Armstrong and M. F. Day. (*Chartered Mech. Eng.*, 1957, **4**, Sept., 346–347). An account is given of N.P.L. work on bolt steels of Cr–Mo, Mo–V and Cr–Mo–V types, pipe and tube steels of Mo–V, 2·25% Cr–Mo and 18–12–1 (Cr–Ni–Nb) types, and a cast Mo–V steel. Only a summary is given.

On the Quality Requirements for Steel Valves for Nuclear Power Plants. J. J. Kanter. (*Amer. Soc. Mech. Eng. 2nd Nuclear Eng. and Sci. Conference*, 57–NESC–33, 1957, pp. 5). A discussion of requirements, inspection, sealing, and specifications for forgings and castings is given.

HISTORICAL

Historical Evolution of Steel Furnaces. G. Grenier. (*Echo Mines*, 1957, July, 406–408). A general account of basic Bessemer, O.H. and electric steel plants. (7 references).

Basic Bessemer Steel, French Steel, Quality Steel. M. Grison. (*Arts et Manuf.*, 1957, Aug.-Sept., 15–17). An historical review of production and developments and advantages of the process.

A Great French Metallurgist: Louis-Emmanuel Gruner. (*Aciers Fins Spec. Franç.*, 1957, July, 125–141; In English, 130–133). A biography.

ECONOMICS AND STATISTICS

Investments in the Steel Industry, Their Financing and their Importance for Production and Productivity. H. Åselius. (*Jernkont. Ann.*, 1957, **141**, (7), 355–379). [In Swedish].

Saving Raw Materials in Ferrous Metallurgy. L. L. Zusman. (*Stal'*, 1957, (7), 644–650). Production in the U.S.S.R. requires $> 200 \times 10^6$ t of raw materials per year. The raw materials are 25–30% of the cost of pig iron, 60–70% of the cost of steel and 80–90% of the cost of rolled products. The relationship $x = a/b$ where a is iron in finished products, b the amount in the raw materials used gives the coefficient of utilization of ion x. Figures for 1955 are given and an iron balance for the Ministry of Iron and Steel with and without returned scrap. Yield figures for 1939, 1951 and 1955 are also given with coefficient of utilization for the different plants, also iron in scrap per t good ingots for 1946.

Materials-Flow Recording and Manufacturing Programme as an Aid to Management and Efficiency in Iron and Steel Works. W. Schütte, U. Sabass, H. H. von Lintig, and A. Schütz. (*Stahl u. Eisen*, 1957, **77**, Aug. 8, 1045–1064; Aug. 22, 1146–1160). The authors describe in great detail the internal accounting and recording system, including supervision of smelting, melting and refining processes and the working at the various stages, as used by the August-Thyssen-Hütte Duisburg-Hamborn. From the metallurgist's point of view, the various card records are of great value for statistics.—T. G.

MISCELLANEOUS

Predicting Future Nickel Consumption. H. D. Lytton. (*Eng. Min. J.*, 1957, **158**, Aug., 86–89, 226).

Spanish Tungsten for the World. J. L. Rodriguez Pomatta. (*Met. Elect.*, 1956, **20**, Jun., 139–143). [In Spanish]. The political economy of tungsten is discussed, and principles for its international control in the Western world are listed.

BOOK NOTICES

ASSOCIATION OF BRITISH CHEMICAL MANUFACTURERS. "*British Chemicals and Their Manufacturers.*" 8vo. pp. 200. London, 1957: The Association.

This is the latest of the annual volumes issued by the A.B.C.M. giving a directory and classification of member firms, a list of products, with a separate section on indicators and microscopical stains and an addendum on redox indicators, a list of proprietary and trade names and reproductions of trade marks. Nomenclature is based on B.S. 2474 : 1954, and the chemicals, of which the great

majority are organic, are given in alphabetical order. The 55 pages of trade names include much information difficult to obtain elsewhere in readily available form, and may be of wider interest than the list of products, which will appeal mainly to buyers. So far as they can be checked the lists appear to be complete and the volume is up to the very high standard to be expected from its sponsors.—J. G. C.

BOURDON, H. *Acieristes et Fondeurs. Le Four Electrique Basique.* 8vo. pp. xvii + 114. Illustrated, Paris, 1957: Dunod. (Price 800 fr.).

This little manual on the basic electric furnace is written essentially for the man who actually makes the steel. Its author is a steel plant manager.

The preamble deals briefly with the basic principles of, and the essential equipment for, this type of furnace. This section is rather sketchy and incomplete—for instance, it mentions only the old style of automatic electrode regulation, which bears no resemblance to the automatic controllers installed on modern arc furnaces.

Much of the next twenty-two pages, dealing with the historical development of the arc furnace, could, with advantage, have been omitted. Many of the systems described were never applied, and contributed little to the development of the present-day arc furnace. Emphasis is rightly laid on the work of the great French pioneers—Héroult, Keller and Girod—but the names of Greaves and Etchells, Moore and Gronwall, who made great contributions to electric melting, are not even mentioned. Chapter III deals in detail with the constructional features and operation of the Héroult-type furnace; even here certain important omissions were noted.

The section on steel and steelmaking is very competently and clearly written. The chemical reactions and the various operations involved in the basic electric process are made intelligible even to those with only a rudimentary knowledge of metallurgy; relatively recent developments, such as oxygen blowing and immersion pryometry are included.

The next chapter deals with ladle and ingot practice, and many practical points such as segregation, piping, and ingot defects are excellently treated. There are, however, one or two loose generalisations, such as the remark that "the action of killing agents is based upon increasing the solubility of the gases in the liquid metal." This is probably due to the author's attempt at over-simplification.

Then the author touches on the principal types of alloy steels made in the arc furnace, and one notices that chrome–vanadium steels have been omitted. He also makes a statement which may be applicable to France but certainly does not represent British and American practice, namely, that 18/8 stainless is only produced in the arc furnace by a few well-equipped steelworks. In the U.S.A. and Great Britain the bulk of this steel is made in the arc furnace. Otherwise this section is very well written, and the author gives some useful examples of the procedure adopted for making a stainless-steel heat and also a melt of high-speed steel.

The book ends with some useful information on ferro-alloys.

Considering its modest price, it is well produced and illustrated with 43 line diagrams. In view of the increasing use of electric melting, a book covering the same field in the English language would serve a useful purpose.—A. G. ROBIETTE.

CREMER, H. W. and T. DAVIES (Editors). "*Chemical Engineering Practice.*" Vol. 2. "*Solid State.*" 8vo. pp. vi + 632 + xxiii. Illustrated. New York, 1956: Academic Press Inc.; London: Butterworths Scientific Publications. (Price, $17·50).

This is an excellent text-book from what promises to be an excellent series. Though there is no Preface to define its scope it is obviously a work for the advanced student, and, without obvious compression and with clear printing (and a good index) it covers the very wide field by means of chapters by different authorities of a very uniform quality and to a comparable standard of advancement. It is directed to the needs of the chemical engineer and so is much concerned with metallurgy and scarcely at all with the inorganic crystal, from which two fields, of course, our knowledge of the solid state has come. The chapters of interest to the metallurgist are noted in the Abstracts Section, this J. p. 88, passing over, to some extent, non-ferrous topics. The other chapters are: **Mechanical and Physical Properties of Plastics and Glasses,** by H. T. Hookway, (pp. 242–254). **Porous Masses,** by P. Eisenklam, (342–463). **Important Industrial Uses of Porous Masses: The Purification of Coal Gas,** by G. V. Hopton; **Flow in Fuel Beds,** by H. G. Crone; **The Use of Porous Masses in the Treatment of Water and Sewage,** by F. E. Bruce; **Transpiration Cooling,** by P. Eisenklam, P. Grootenhuis and H. Ziebland, (533–632). The book has a notably practical approach and is without the more abstruse mathematics and physics in which the more recent studies of the subject have been expressed.—J. G. C.

"*Metallurgical Progress*—3." 4to. pp. 88. Illustrated. London, 1957: Illife & Sons Ltd. (Price, 6*s*.).

This is a third series of critical reviews reprinted from "*Iron and Steel*" and contains 7 articles as follows: "Refractories in the Iron and Steel Industry" (in four sections), by Helen Towers; "Non-Destructive Testing" (Surface Condition, Ultrasonic Testing and Radiography), by J. M. McLeod; "Metallurgical Coke 1939–1955," by J. Taylor; "Foundry Sand Practice," by W. B. Parkes; "Reducing the Phosphorus Content of Foundry Iron," by R. I. Higgins; "Ironfoundry Metal Melting Furnaces," by Frank Dunn; and "Mechanical Properties of Flake Graphite Cast Irons," by G. N. J. Gilbert. These are authoritative articles of considerable interest; abstracts of them have already appeard in the columns of the *Journal* of the Institute.—J. G. C.

GUDTSOV, N. T. and M. N. GAVZE. "*Action of Mercury on Steel in Power Plants.*" 8vo, pp. 147, Illustrated. Moscow, 1956: U.S.S.R. Academy of Sciences Press.

The constant efforts of fuel engineers to improve the efficiency of fuel led to the development of high productivity mercury-water binary cycles. The use of atomic power requires high potential heat carriers. Mercury has many advantages in this direction.

This monograph discusses the reactions of iron with mercury and the effect of mercury on steel at high temperatures and pressures. The applications of mercury in power plants, metallurgical plants and atomic energy installations is reviewed. The nature of the amalgams of iron and the mutual solubility of mercury and iron and the behaviour of steel vis-a-vis mercury as regards scaling behaviour at high temperatures are discussed. Providing oxygen is not present, mercury is not an aggressive medium at temperatures ranging from room temperature to 900–1000° C. Duration of contact between steel and mercury does not in itself affect this fact. Neither is there any real danger of the penetration of mercury to the steel grain boundaries. In the presence of oxygen, however, mercury will penetrate the pores of the scale coating and the non-scaled steel surface, at high temperature. In carbon steels, the scale retains the mercury in the pores and adsorbs it at the surface thus preserving the bond with the entire mass of mercury and depriving it of its mobility. The effect of mercury on steel therefore, is determined, at high temperatures, by the nature of the scale formed at the surface of the steel, the main factor being the density and strength of the oxide layer and the adhesion between it and the steel surface. The nature of scaling in mercury contact conditions at high temperature is described in relation to different types of steel.

This book should be a useful addition to published data in this field. Much tabulated data are included. However, like most Russian technical books, it lacks an index.

R. SEWELL.

RUDDLE, R. W. "*The Solidification of Castings.*" (Institute of Metals Monograph and Report Series, No. 7.). Second revised edition. 8vo, pp. 406. Illustrated. London, 1957: The Institute of Metals. (Price 42*s*. ($6·50)).

This new edition surveys and critically reviews the extensive literature on the solidification of castings published up to the early part of 1956, giving more than 300 references, of which nearly half have appeared since the first edition was published.

The very wide field is dealt with under eight main chapter headings, beginning with the various experimental methods that have been used and a discussion of their relative advantages and disadvantages. Chapter II gives a very lucid discussion of the mechanism of solidification of pure metals, solid solution alloys and eutectics, and the

calculation of the temperature distribution in castings by analytical or approximate solutions of the differential heat-flow equation is described in Chapter III. Heat extraction by sand and chill moulds is dealt with in Chapter IV, leading to a discussion of solidification rates in such moulds in Chapters V and VI. Chapter VII deals with the solidification of continuous castings and the final chapter with the practical application of the theoretical and practical work to the production of sound castings. There are also two appendices giving useful data on the thermal properties of metals and mould materials and on two of the mathematical functions used in the calculation of temperature distribution.

The author has succeeded in making each of these chapters very nearly self-contained and few criticisms can be made. There are a number of footnotes which tend to distract the reader and could perhaps have been advantageously incorporated in the text. It is also felt that the description and discussion of the analogue methods of solving the heat-flow equation would be more appropriate in Chapter III than in Chapter I. Somewhat surprisingly, no mention is made of vacuum casting, but apart from this the subject is adequately covered, generally in sufficient detail to make reference to the original papers unnecessary.

The book is well illustrated and adequately indexed, and, apart from the minor point of footnotes, reads very easily. It should prove invaluable to research workers and foundry metallurgists and also to the more practical foundryman who wants to know what goes on in casting practice.

L. H. W. SAVAGE.

AMERICAN SOCIETY FOR METALS. *Review of Metal Literature*, 1956." Prepared by The Technical Information Division of Battelle Memorial Institute, Columbus, Ohio, U.S.A.; Marjorie R. Hyslop, Editor. 8vo, pp. X + 859. Cleveland, Ohio, 1957; The Society. (Price $15.00).

This, Volume 13 of the series, contains about 8450 abstracts of metallurgical literature of periodical, report and book form, from a wide range of American and "foreign" sources. They are of an indicative rather than informative nature; the coverage is extensive, and deals with all aspects of the production, refining, properties and applications of most common, and many rare, metals. The subject headings are too broad to give a very fine classification, but they are supplemented by a subject index; there is also an author index and a useful list of the publication addresses of the journals and reports cited. References quoted by American writers on metallurgical subjects are often lacking in important material from European and other "foreign" sources; were they to consult the "Reviews of Metal Literature" American authors would find the key to a store of valuable information, much of which is apparently unknown to them.—J. P. S.

BAILEY, A. R. "*A Text-Book of Metallurgy.*" Revised and Reprinted. 8vo, pp. viii + 560. Illustrated. London, 1956; Macmillan & Co., Ltd.: New York: St. Martin's Press. (Price 30*s*.)

This book sets out to provide a comprehensive and up-to-date textbook for students taking introductory and general metallurgy in Degree, Technical College and Institution of Metallurgists Courses. The general plan of the book is that the structure and properties are dealt with in six chapters. These cover the atomic and crystal structure; the background to binary alloys and constitutional diagrams; the effect of stress on metals; and the methods for the examination of metals such as microscopy and X-ray analysis. There are then three chapters on extraction and refining techniques for metal production. Finally, there are separate chapters on metal casting, mechanical working processes, mechanical testing and pyrometry.

The main object of this type of book must be to interest a student in the various topics covered and to indicate whether a more extended study is useful. The author can claim to have accomplished this successfully. The structural aspects of metals are dealt with concisely but adequately, and these chapters are well illustrated with photomicrographs and equilibrium diagrams. On the process side, too, with a combination of concise description and extensive illustration, a very good general impression of the processes for extracting and fabricating metals is given.

It is inevitable in a book of this type that a reviewer will consider some important aspect has been inadequately covered. This criticism is levelled at the treatment given to the mechanical properties of metals and alloys. It may, in fact, be a reflection of the way in which the curriculum for the various examinations is drawn up, but throughout the book the final product is almost ignored. This is unfortunate, because it is felt that at the general level there are many more metallurgists using metals than extracting and refining them. A warning must therefore be given that this book must be supplemented by a further book on the properties and applications of metals and alloys if a student wishes to have textbooks providing an introduction to metallurgy.

Apart from this aspect, however, the book does provide a useful introduction to metallurgy at a reasonable cost.

K. J. IRVINE.

COLOMBIER, L. "*Métallurgie du Fer.*" Deuxieme édition. Préface de P. Chevenard. La 8vo, pp. xv + 429. Illustrated. Paris, 1957: Dunod. (Price 3900 fr.).

In this book of 429 pages, the author has endeavoured to cover every aspect of the manufacture of pig iron, wrought iron, structural steels and even high-alloy steels. In such detail has he endeavoured to deal with his subject that several pages are devoted to the Walloon and Lancashire process for the production of wrought iron and to the puddling process. He likewise considers the continuous casting of steel and casting in a vacuum.

The book is divided into four parts and the fourth part which consists of only 60 pages is divided into four chapters, in which the author considers, *inter alia*, the influence of nickel, silicon, aluminium, manganese, chromium, tungsten, molybdenum, vanadium, titanium and cobalt on the properties of steel, and the final chapter of 10 pages even covers corrosion-resisting alloys. The other three parts are equally wide in their scope.

It will hence be appreciated that the book is extremely superficial and is not one that will appeal to English metallurgists. It can, however, be said in its favour that it is written simply and clearly.—J. FERDINAND KAYSER.

GREGORY, EDWIN, and ERIC N. SIMONS. "*The Structure of Steel.*" A Simple Explanation for Students, Engineers, and Buyers of Steel. Third edition. 8vo, pp. 176. Illustrated. London, 1957: Odhams Press, Ltd. (Price 18*s*.).

The sub-title states that this book is intended to be simple, and for the use of engineers and buyers of steel rather than metallurgists. It illustrates microstructures and macrostructures by means of twenty-five half-tone illustrations and some excellent line drawings. To explain the implications of "structure," mechanical and non-mechanical methods of testing are fully described, and X-ray diffraction is not shirked. Curiously enough, work-hardening is first described in the chapter on "Corrosion," though the next chapter deals with the "Structural Effects of Mechanical Working," but in any case we are not given an illustration of a cold-worked structure.

The book has been extended and brought up-to-date since it was first published in 1938, and many novel forms of heat-treatment are described. The reader is spared any mention of dislocation theory, but this omission perhaps makes too simple the short explanations given of quench-hardening and strain-hardening.

An excellent Bibliography is provided, and includes a work on the "Austenitic Grain-Size Control of Steel." This particular subject also receives well-deserved treatment in the text. "Shallow-hardening" and "Depth-Hardening" are also dealt with, but the former is not listed in the Index, whilst the latter term seems to be used in two different senses. Considering the excellence of the text the Index might be improved a little, for it contains vague entries such as "discrete particles" and "maximum hardness"; and, whilst it gives "Bessemer steel," there is no reference to other types of steel or to such things as "strain age embrittlement" or "hardenability."

These are relatively minor points in a work which reads very well and which does not hesitate to lead even "a buyer of steel" by gradual steps to the full rigours of the iron–carbon equilibrium diagram.—HUGH O'NEILL.

HIGGINS, RAYMOND A. "*Engineering Metallurgy.*" Part I. "*Applied Physical Metallurgy.*" 8vo, pp. xi + 404. Illustrated. London, 1957: English Universities Press, Ltd. (Price 25*s*.).

The author states the book is intended to provide the necessary basis in theoretical metallurgy for engineering students. This object he has achieved, and the subject is treated in a most satisfactory and adequate manner and reflects the experience of the author in teaching students preparing for qualifications in engineering. The diagrams are clear and informative and the photomicrographs of a high standard, although the reproduction might in some cases be better.

The first chapter deals very briefly with some basic chemical principles which, as the author points out, should assist those engineering students who come to study metallurgy without any previous knowledge of chemistry. This is followed by a chapter on the production of iron and steel in which the principal methods of production are outlined, but it is surprising to find no reference to the high-frequency furnace for the production of highly alloyed steels. Since engineers are concerned mainly with the subsequent use of steel, greater emphasis could have been given to the types and uses of steels produced by the various processes described.

The chapter on physical testing deals only very briefly with the subject, but this is usually covered more adequately by engineering students in other sections of their course. With the developments in non-destructive testing more attention could have been given to this aspect of testing than the extremely brief reference to magnetic dust and X-rays. However, the chapters on corrosion, joining of metals, machinability and measurement of temperature are all adequately dealt with within the scope of the book.

The main section of the book deals with physical metallurgy, starting with the solidification of metals, and development of their crystalline structure, followed by the effects of deformation on this structure. The alloying of metals and consideration of the basic forms of equilibrium diagrams leads to a study of the structures, heat-treatment and properties of the steels, cast iron and commercial non-ferrous alloys. The topics are dealt with in the order in which they would be taught, and in general the text is accurate and sufficiently detailed for the purpose intended, although criticism might be made of the retention of terms like "secondary troostite" in place of the more modern nomenclature in which troostite is confined to the product of quenching and temper martensite is used for the similar dark-etching structures obtained on tempering.

The subject matter of this book is, as may be expected, covered by other text books on metallurgy for engineers and the need for yet another text book in this field may be doubted. However, the treatment given to the subject in this book and the incorporation of chapters on such topics as machinability, together with the useful selection of exercises and examination questions justify the existence of this further book. The inclusion at the end of a chapter of a list of references for further reading would have enhanced its value to those students who wish to pursue their studies of metallurgy to a higher level.

The book is well printed and bound and reasonable in price and can confidently be recommended to students as a text book.—E. G. Cutbush.

Institute of British Foundrymen. "*Typical Microstructures of Cast Metals.*" Prepared by Sub-Committees T.S.40, T.S.41 and T.S.42 of the Technical Council. Edited by G. Lambert. La. 4to, pp. 224. Illustrated. Manchester, 1957: The Institute. (Price 84*s*.).

With the exception of "Atlas Metallographicus" by Hanemann and Schrader which was published in the 1930's this is the most ambitious collection of micrographs available. Unlike its German predecessor this work is of value to the practical man and has a rational plan. The book has three sections, one dealing with cast iron, one with cast steels and one with cast non-ferrous metals. Even the metallographer specialized in one of these fields will find useful information pertaining to the others.

A brief introductory section deals with the preparation of specimens for microscopic examination; the cast iron section reproduces 118 micrographs; the cast steel section has 69 and the non-ferrous section has 107 micrographs. Wherever possible the material chosen illustrates the appropriate British Standard specifications, the specified or typical properties and compositions being accompanied by the actual values obtained on the material illustrated. A brief description is given of each structure. The micrographs are uniformly well reproduced.

Each section of the work was prepared by a separate committee of specialists. This ensures that a balanced survey has been made of the whole field.

The standard text books deal very indifferently with the metallography of the cast metals. This book repairs that situation and is to be recommended to all founders, engineers, users of castings, and students and teachers of metallurgy. It is not an academic exercise but a work of practical importance to all.—H. Morroch.

Miller, G. L. "*Zirconium.*" (Metallurgy of the Rarer Metals, vol. 2). 8vo, pp. xxi + 548. Illustrated. London, 1957: Butterworth's Scientific Publications. (Price 70*s*.).

As Dr. Miller says in his preface, there has been, since the first edition of this book, a considerable release of classified information on zirconium; this is indicated in the 43% increase in the length of his text. He has been enabled to make substantial increases at all points, the greatest being in the sections dealing with the physical, structural, and mechanical properties of the metal, and of its alloys, which have been doubled in length. Nor has the work been solely of addition, for there are everywhere the signs of careful revision and of the substitution of the accepted for the doubtful; the statement made by this reviewer in 1954, that the first edition would long remain a basic text, has been nobly falsified, and it would not be wise, with the study and technology of zirconium advancing at their present rate, and Dr. Miller having so firm a grip of both, to make a similar prophecy again.—J. P. S.

Parker, Earl R. "*Brittle Behavior of Engineering Structures.*" Prepared for the Ship Structure Committee, under the general direction of the Committee on Ship Steel, National Academy of Sciences—National Research Council. La. 8vo, pp. xv + 323. Illustrated. New York, 1957: John Wiley & Sons, Inc.; London: Chapman & Hall, Ltd. (Price 28*s*.).

This book, prepared for the American Ship Structure Committee, sets out to summarize the available information on the brittle behaviour of steel. The awakening of interest in the brittle-fracture problem is traced from the alarming number of failures in large all-welded ships during the second World War, and the book goes on to discuss in detail the role which various factors are now considered to play in contributing to brittle behaviour.

On the theoretical side, the effect of notches in producing complex tri-axial stress systems is discussed, together with the mechanism of shear and cleavage fracture. Reference is also made to some of the more recent theories of fracture without elaborating upon them.

Testing methods and specimens are described generally, without details of individual testing procedures. Certain of the tests referred to may be unfamiliar to some readers, whereas no direct mention is made of tests better known in Britain, *e.g.*, Tipper or Van der Veen tests. In discussing difficulties in the interpretation and correlation of test results the importance of the ductile-brittle transition criterion chosen is emphasized. In particular, distinction is made between "ductility transition" criteria, associated with the ability to flow plastically before fracturing, and "fracture transition" criteria, associated with the manner in which the crack propagates.

Chapters are devoted to the effects on notch ductility of chemical composition and manufacturing practice, welding, residual stresses, and design and workmanship. Not all of the statements made regarding these will find universal acceptance, but this is scarcely surprising, considering the diverse views which are still held on many aspects of the subject. The book also includes an extensive review of the major service failures which have occurred in both ships and other engineering structures.

One criticism which might be made of the volume is that, while it is intended to "summarize the available information," very little reference is made to work other than that carried out in the United States. Nevertheless the book presents a clear and readable account of the main features of the brittle-fracture problem and the extent to which these have been investigated.—R. Kennedy.

VEREIN DEUTSCHER EISENHÜTTENLEUTE. "Werkstoff-Handbuch Stahl und Eisen," 3. Aufl., 1953. "Ergänzungen I." Ausgabe August, 1957. 8vo, pp. 26. Illustrated. Düsseldorf, 1957: Verlag Stahleisen m.b.H. (Price D.M. 3.50).

These extensions to "Werkstoff-Handbuch Stahl und Eisen," reviewed in *J. Iron Steel Inst.*, 1954, **176**, Apr., 479, consist of a number of loose-leaf pages. The first details a number of minor corrections, and the second and third extend the contents headings and subject index respectively. The rest of the material consists of a revised table on hard and soft solders for iron and steel, and form entirely new articles. These are (i) Rapatz and Daeves on "The Characteristic Effects of the Alloying Elements in Steel," (ii) Reich on "Molybdenum Steels," (iii) Buhler on "The Measurement and Removal of Residual Stresses" and (iv) Martin and Werner on "Ultrasonic Testing." These articles are of a high quality and form valuable additions to a useful work.—J. P. S.

NEW PUBLICATIONS

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AMERICAN FOUNDRYMENS' SOCIETY. "*Recommended Safety Practices for the Protection of Workers in Foundries.*" Second edition. La. 8vo, pp. iv + 54. Illustrated. Des Plaines, Ill., 1957: The Society.

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AMERICAN SOCIETY FOR TESTING MATERIALS. "*Report on Elevated-Temperature Properties of Wrought Medium-Carbon Alloy Steels.*" Data Compiled and Issued under the Auspices of the Data and Publications Panel of the ASTM–ASME Joint Committee on Effect of Temperature on the Properties of Metals. Prepared for the Panel by Ward F. Simmons, and Howard C. Cross. ASTM Special Technical Publication No. 199. La. 4to, pp. iv + 123. Illustrated. Philadelphia, Penn., 1957: The Society. (Price 35*s.*).

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"*A History of Technology.*" Volume III. "*From the Renaissance to the Industrial Revolution,* c. 1500–c. 1750." Edited by Charles Singer, E. J. Holmyard, A. R. Hall and Trevor I. Williams, assisted by Y. Peel and J. R. Petty. La. 8vo, pp. xxxvii + 766. Illustrated. Oxford, 1957: Clarendon Press. (Price 168*s.*, U.K. only).

HOT DIP GALVANIZERS ASSOCIATION. "*General Galvanizing. A Manual of Good Practice.*" La. 8vo, pp. 56. Illustrated. London, 1957: The Association. (Price 25*s.*).

INSTITUTE OF BRITISH FOUNDRYMEN. "*Typical Microstructures of Cast Metals.*" Prepared by Sub-Committees J.S.40, T.S.41, and T.S.42 of the Technical Council. Edited by G. Lambert. La. 4to, pp. 224. Illustrated. Manchester, 1957: The Institute. (Price 84*s.*).

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Revolving Frame and Bridge Casting for 22-RB excavator. Weight as cast 2 tons 14 cwt. Sectional thickness max. 2½" min. ½". Cast for Ruston-Bucyrus Ltd., by whose permission it is reproduced.

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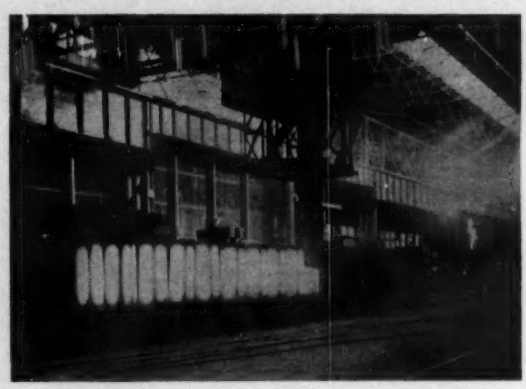

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SQUARES 6G. TO $\frac{7}{16}$″
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(I/D 28″ O/D 36″)

ROD CONVEYOR

Ladle Cranes

Stripping Cranes

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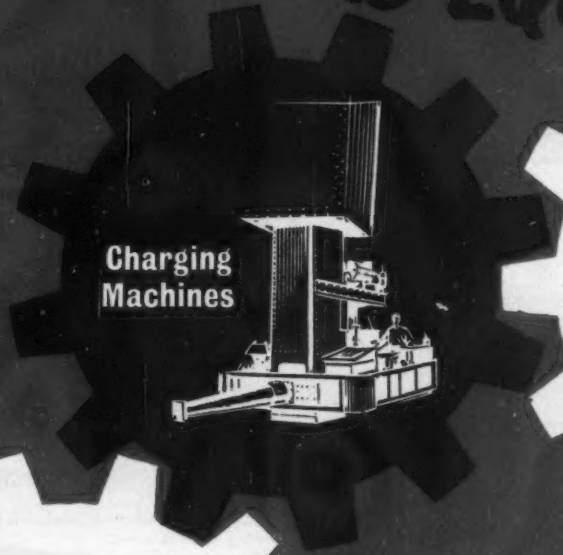

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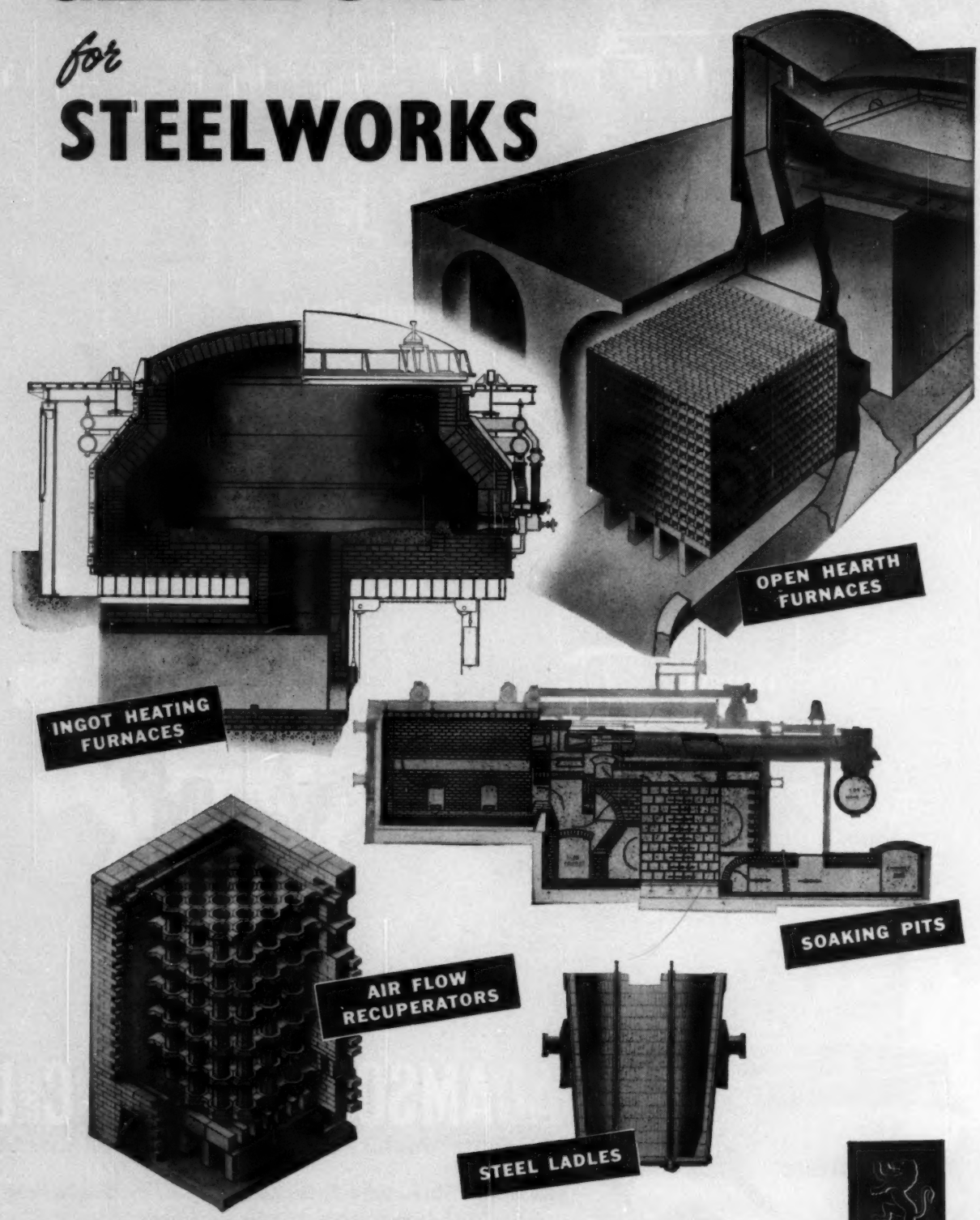

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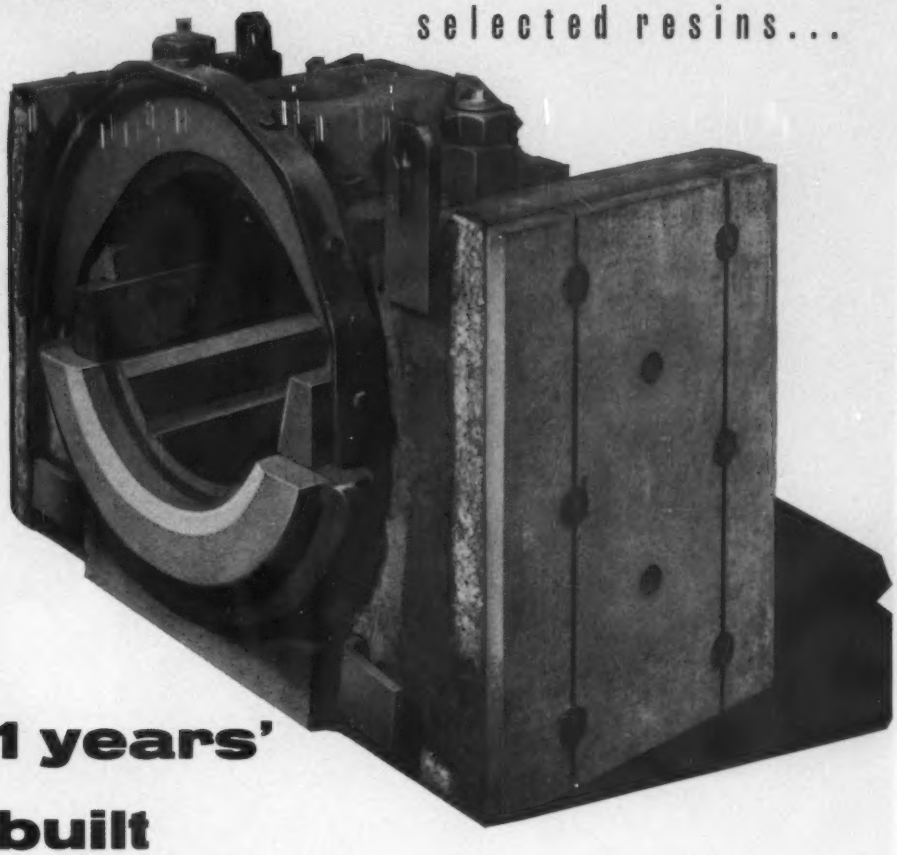

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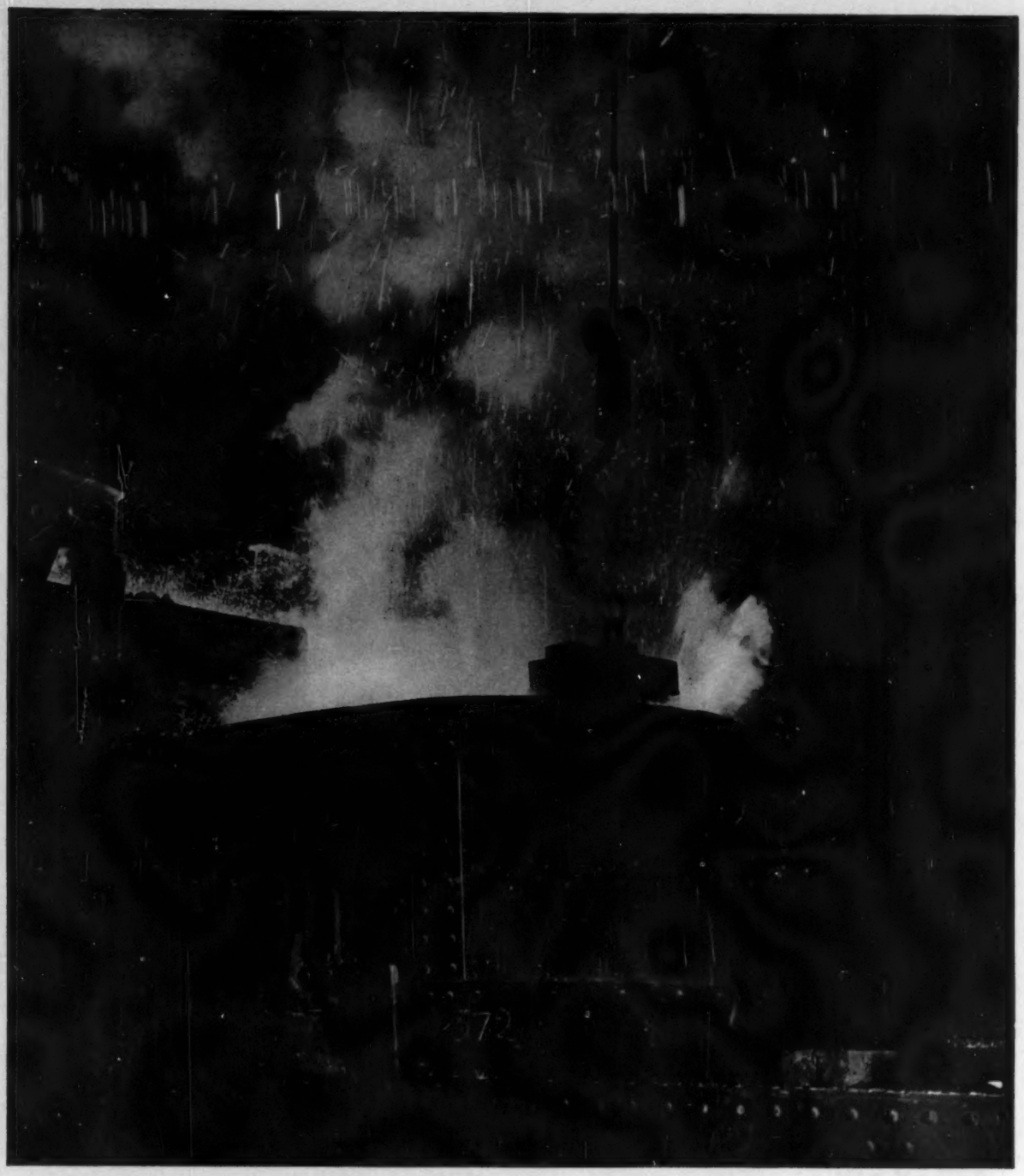

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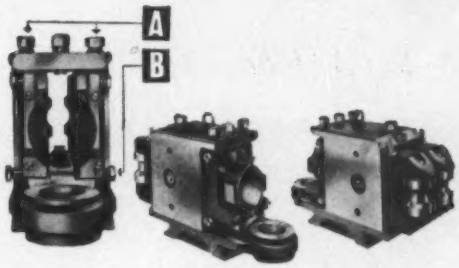
3 If the thickness of the oval should vary, the springs of both rollers yield an equal amount, so that the oval remains in the centre of the groove.

4 To tilt the oval, the screws "A" are adjusted. One roller will then be lifted as much as the other is lowered.

5 As the oval is held very rigidly, the leader oval for wire rod may be thick, unless other circumstances call for a thinner oval.

6 The roller guide assemblies are narrow, and all screws that require adjustment during rolling are accessible from the front of the mill. No lateral space outside the guide box is therefore required for gaining access to the set screws, and the guide box assembly can thus be located close to the mill housing.



7 As the groove in the entry guides is wide and nothing but rolling friction acts on the oval, the latter is very easily introduced into the pass, and there is practically no risk of scratching the bar.

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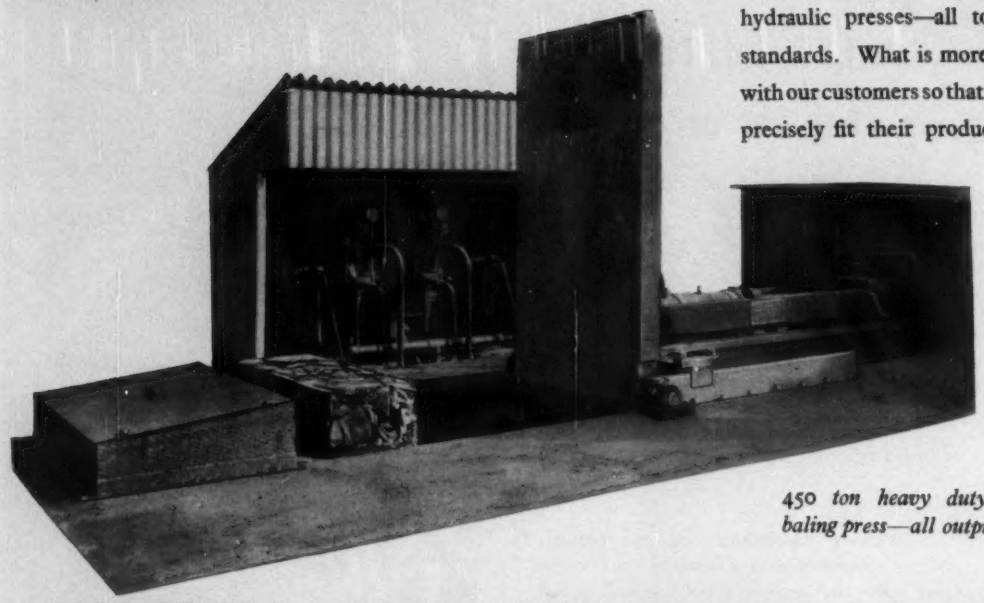

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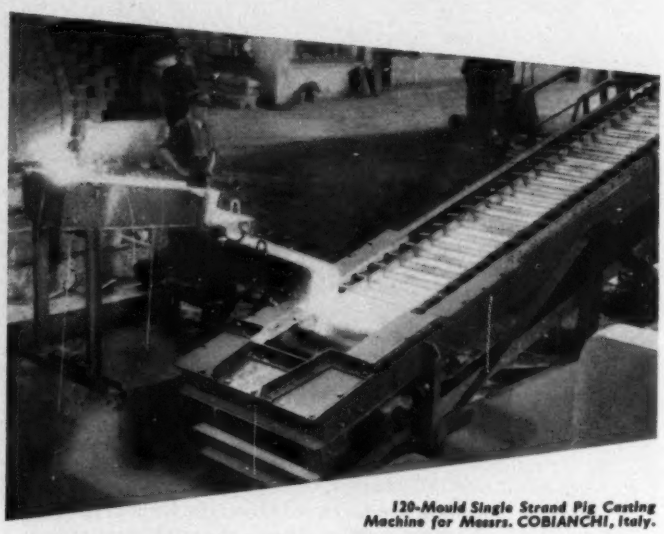
PIG IRON CASTING MACHINES



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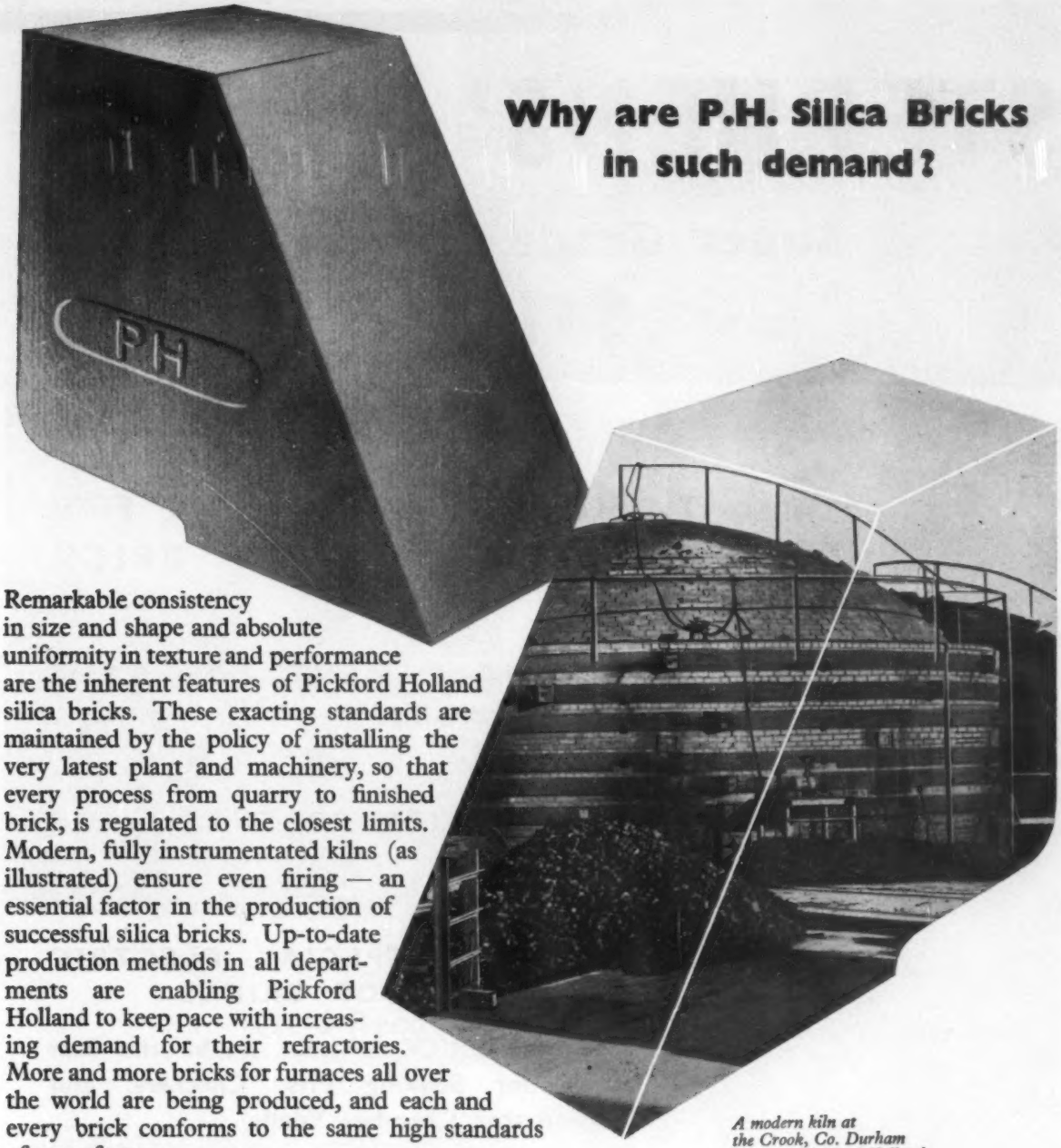

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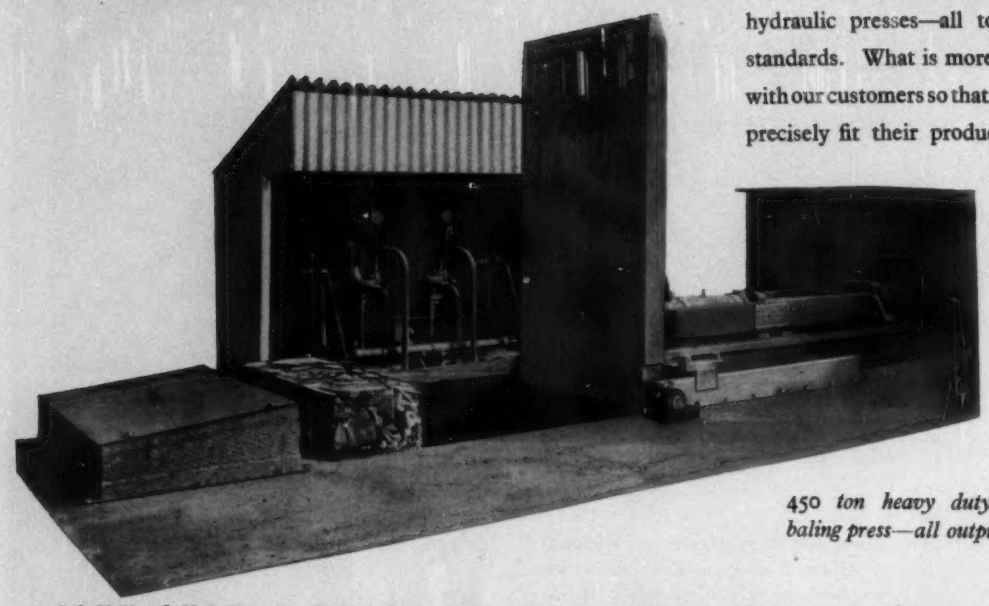

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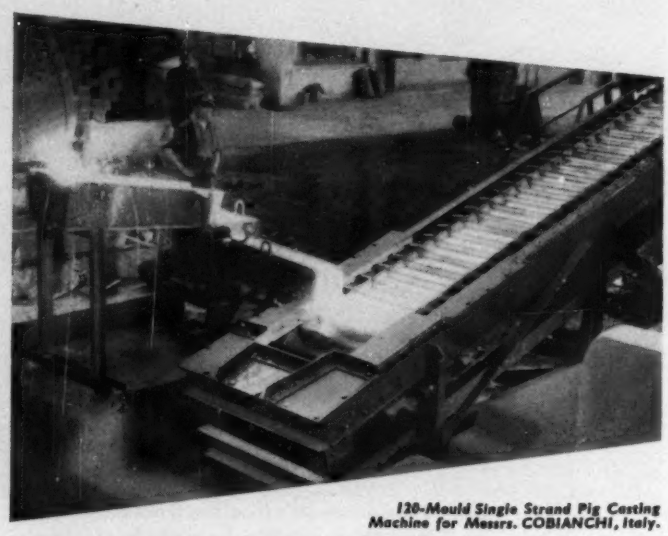

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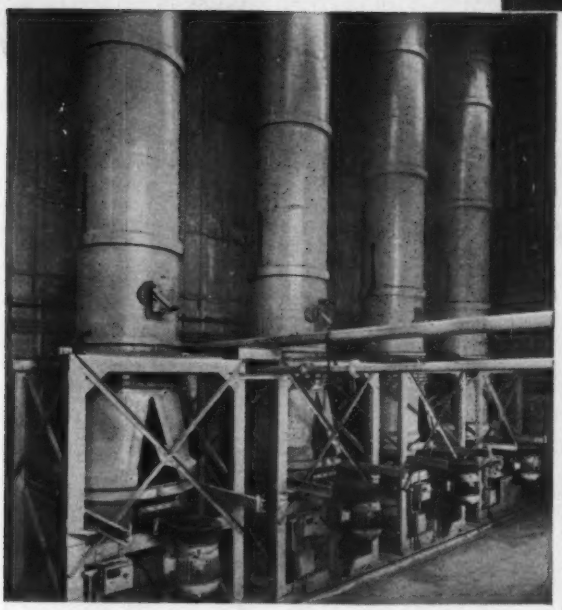

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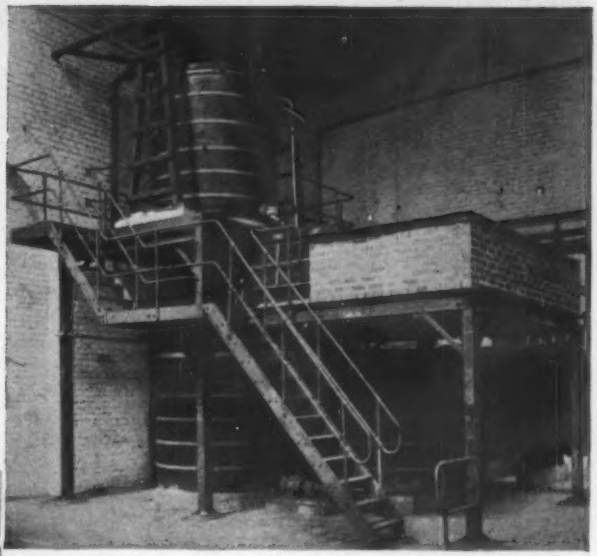
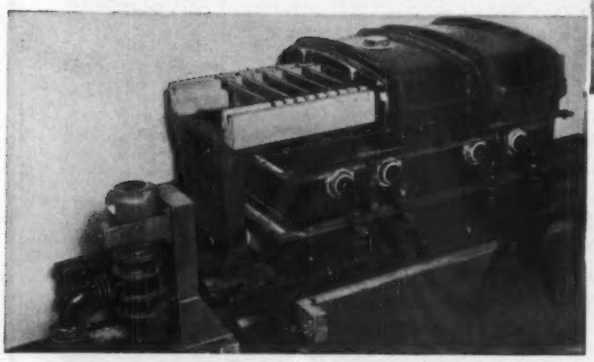


Acid Recovery

Ferrous or non-ferrous industries



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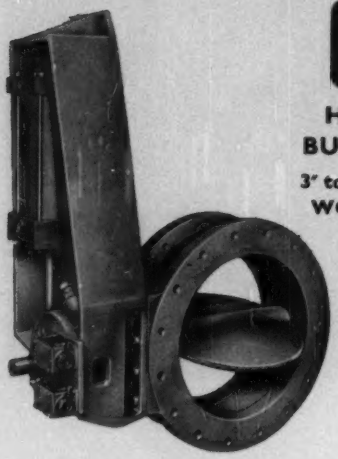

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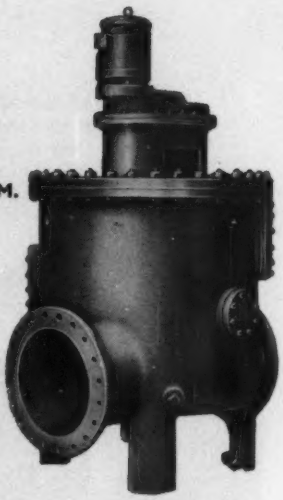

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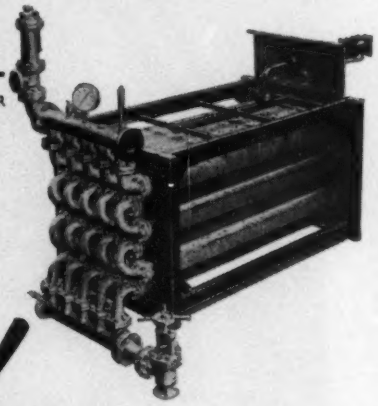

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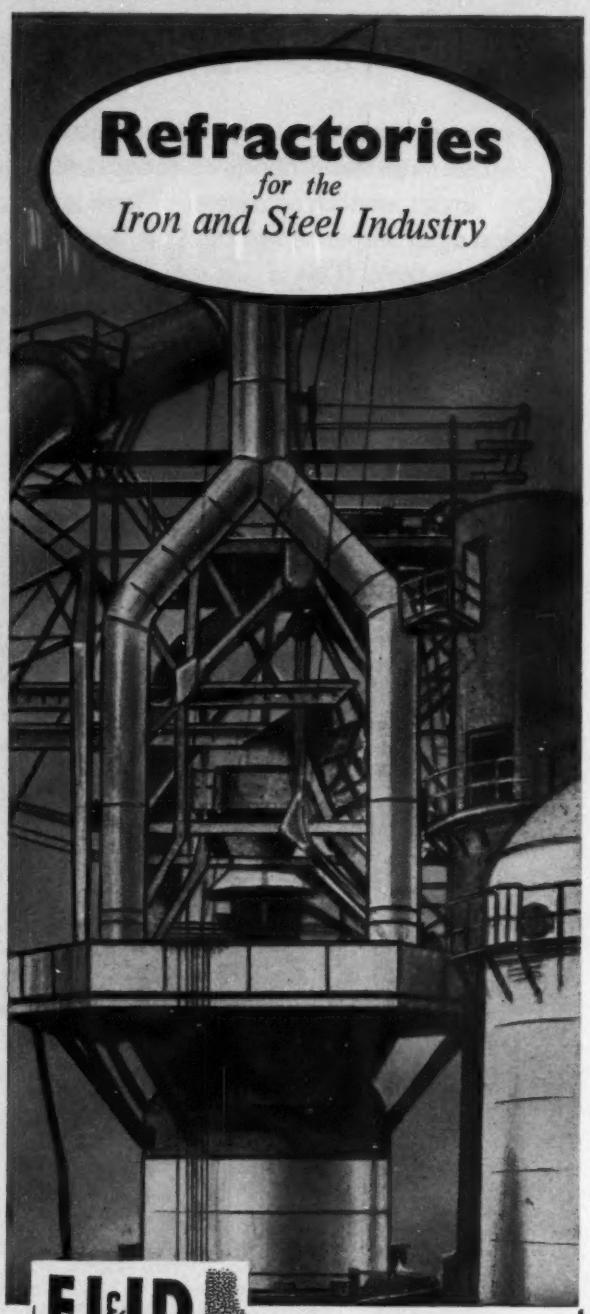

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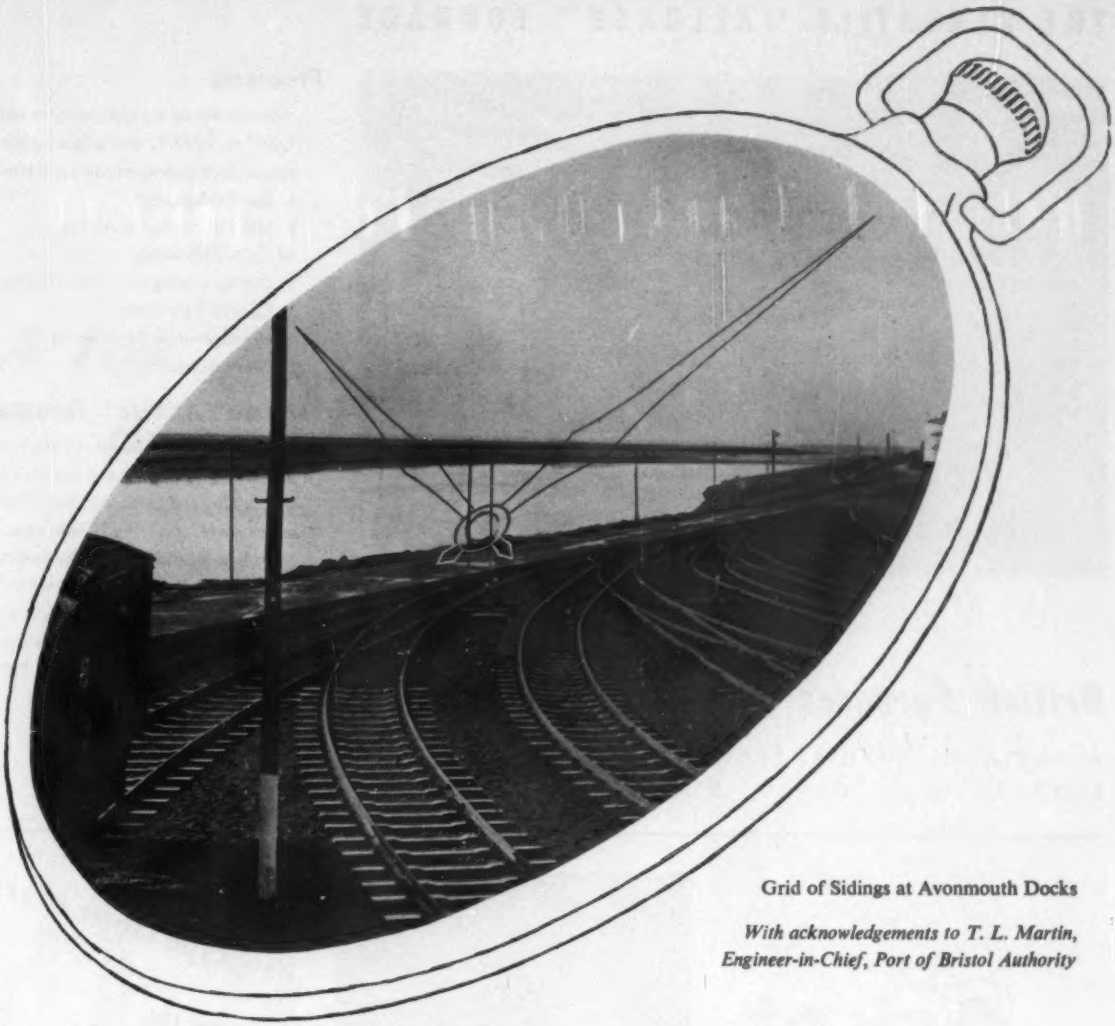

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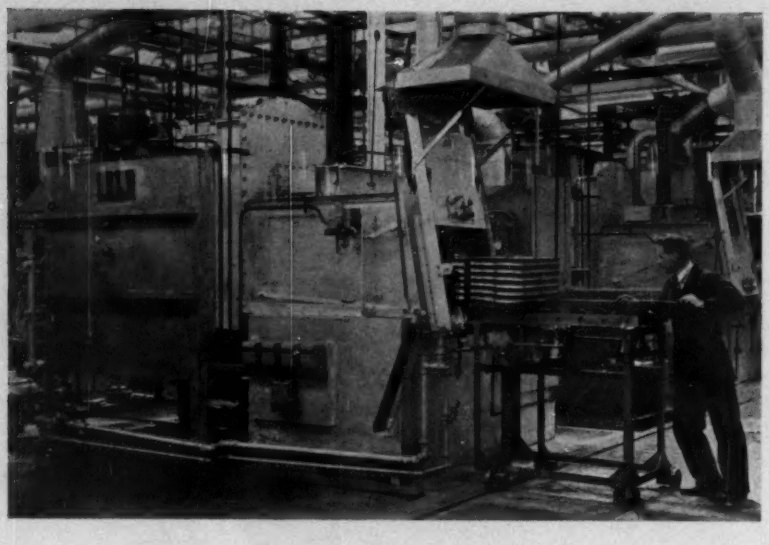

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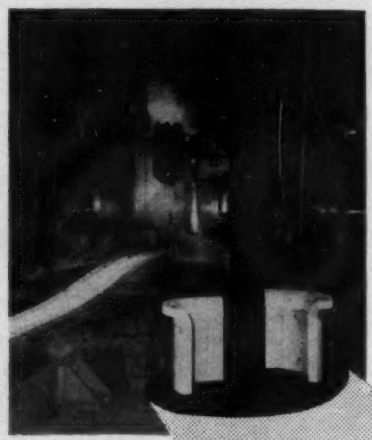

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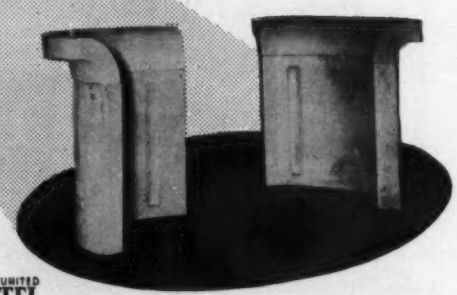

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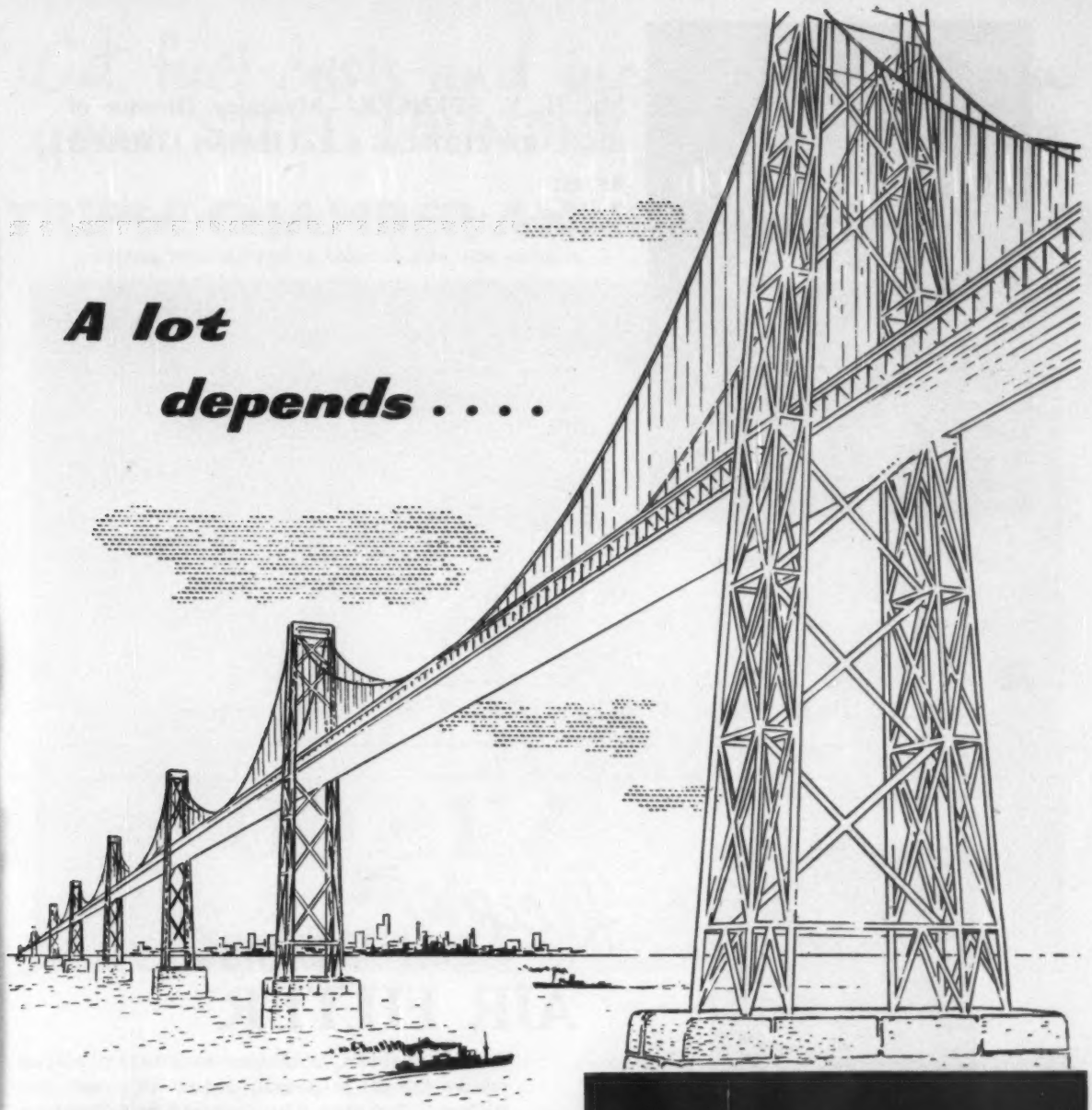

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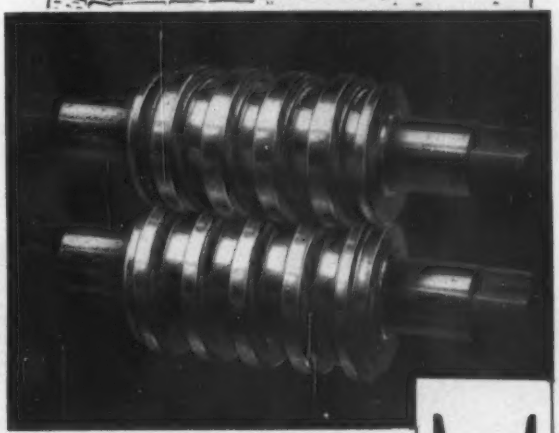

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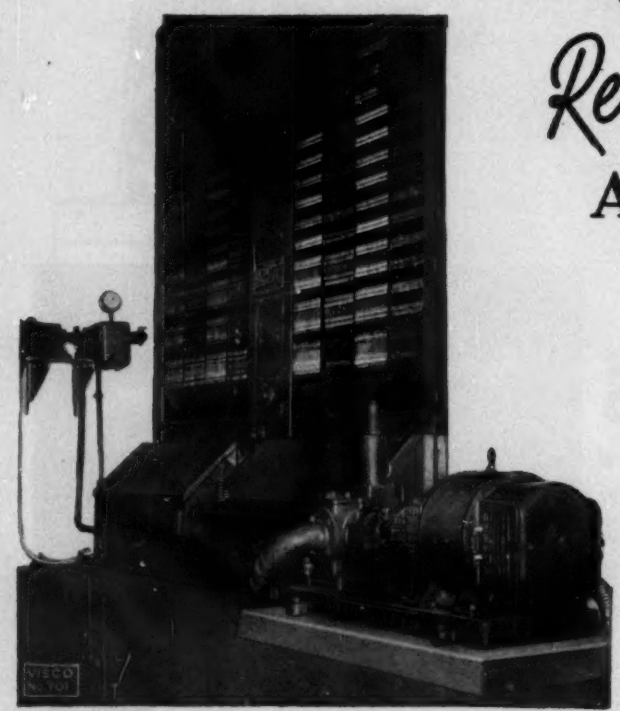

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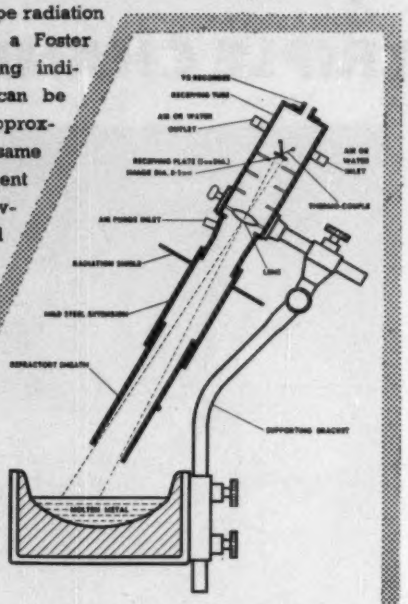

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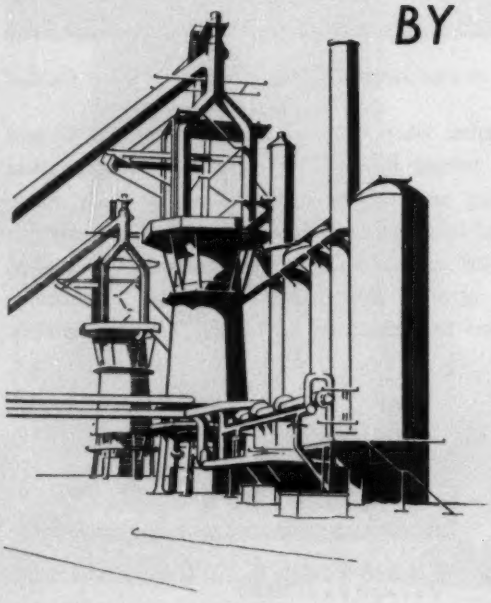

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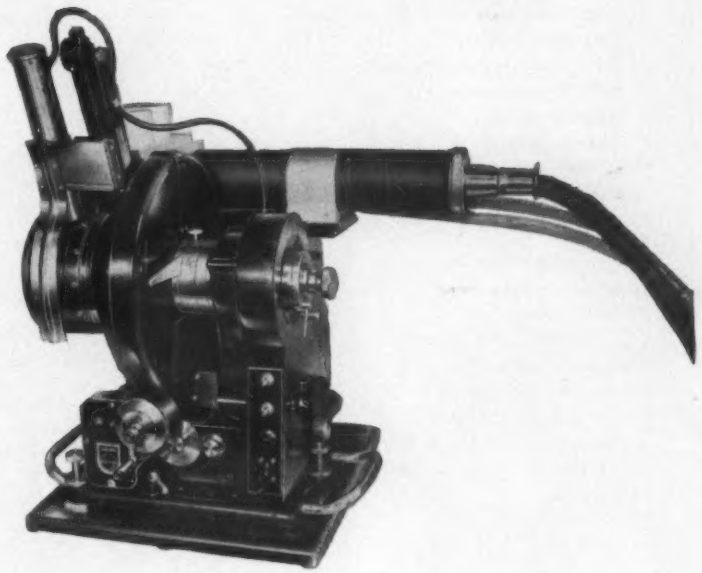

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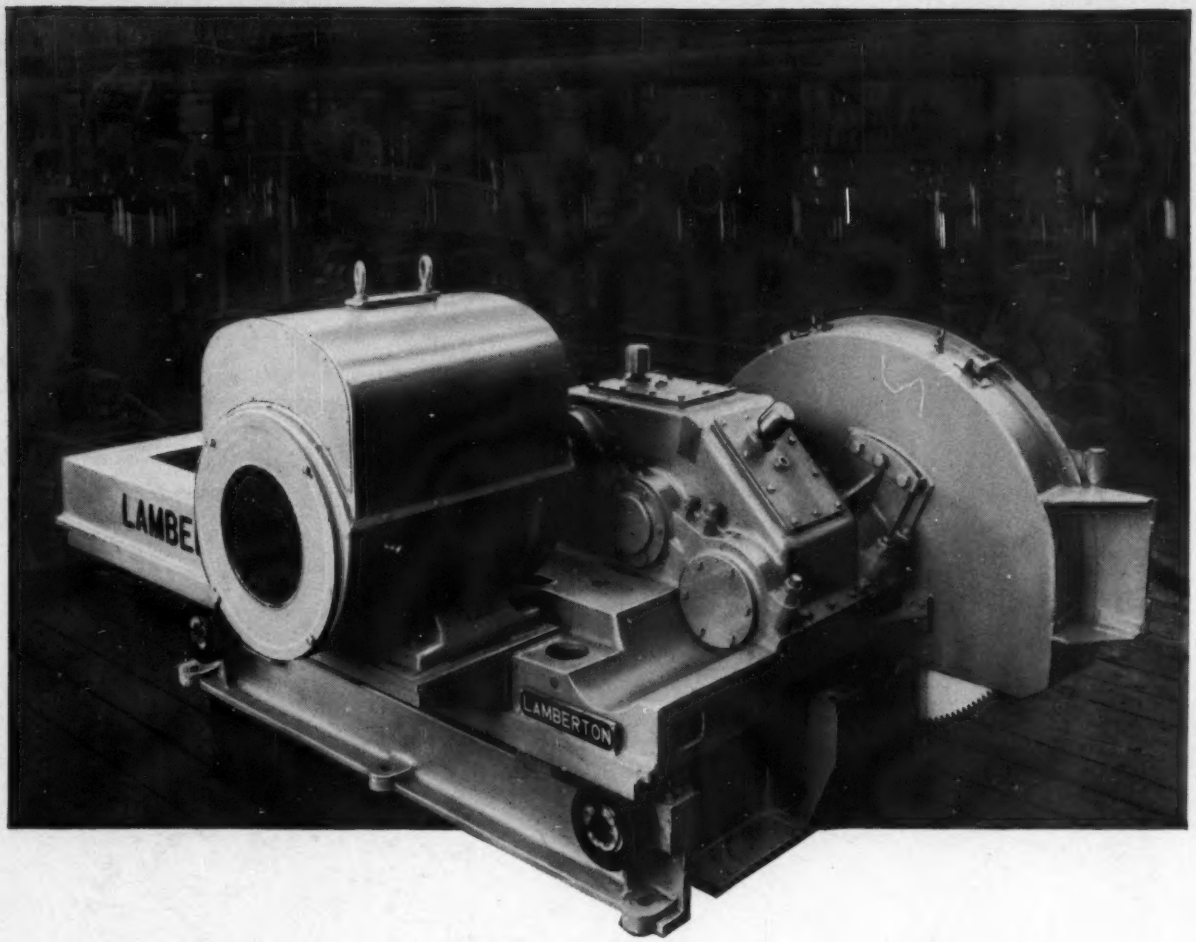

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